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Journal of the
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EARLY SOIL-CEMENT RESEARCH AND DEVELOPMENT

Miles D. Catton,[1] M. ASCE

SYNOPSIS

The following account is devoted primarily to a technical explanation and discussion of (1) the scientific and engineering principles applied, and (2) the testing procedures evolved in the Portland Cement Association's research and development work on mixtures of soil and cement. These resulted in the successful development of a new structural material (soil-cement) whose physical characteristics could be predicted and controlled and which could be constructed at low cost. This account is preceded by a brief history of the use of cement with soils.

Early Work

The origin of the idea of mixing soil and cement to produce a structural material has not been definitely established. The first record in the United States involves a patent for "Soilamies" issued in 1917 for highway use and it can readily be conjectured that ideas, and even efforts, to mix soil and cement preceded this date. In 1920 another patent was issued for "Soilcrete" for highway use. Informal records show that mixing soil and cement was tried in Iowa, Ohio, Texas and probably in other places in the next decade. However, none of these records or experiences produced a material of known or predictable characteristics that could be quantitatively evaluated by laboratory tests nor were construction procedures outlined by suitable specifications.

In 1932 the South Carolina State Highway Department in a search for low-cost, all-weather roads, began investigations of mixing soil and cement under the leadership of the late Dr. C. H. Moorefield (M. ASCE) while Chief Highway Commissioner. Road trials were made in 1933 and 1934. Generally, a varying

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thickness of hardened material was produced that did not rut or displace in wet weather or disintegrate and return to mud during the winter. While the causes of the soil and cement reactions remained illusive, the field performance of these trial projects clearly demonstrated that soil and cement were compatible materials and that they could be mixed (processed) together to form a usable road.

This impressive experience of the South Carolina State Highway Department was brought to the attention of the Portland Cement Association. On January 1, 1935 the Association formally began a scientific investigation to uncover the basic relations of soil and cement with the specific objective of producing a predictable, low-cost construction material that could be used for light traffic paving. This was accomplished in following years.

The use of soil-cement as a construction material is now commonplace in the United States. It was used by many countries overseas during World War II and subsequently has undergone laboratory investigation, evaluation, and extensive use in several countries. All this activity has contributed materially to the understanding and acceptance of soil-cement, has reinforced and verified many of the basic concepts of soil-cement relations, testing, and use which are discussed in this paper, and has contributed new knowledge of soils, of cement, and of their relationships. Tribute and acknowledgement of this work is accorded in this manner in lieu of a bibliographical citation of the work, which, by itself, could not do full justice to it.

Properties of Soil-Cement

The following account will be largely confined to a technical interpretation and explanation of a "philosophy" of soil-cement technology resulting from the Portland Cement Association's research, testing, development, and construction program with which the author was intimately associated and which he developed and directed during the years 1935-49. In the discussion will be found citation, analysis and acknowledgment of much valuable work performed by others during and subsequent to this period and which is continuing at an accelerated rate parallel to the use of soil-cement.

Soil-cement is a material having its own unique properties. Therefore, at the outset it is suggested that comparisons of soil-cement and the technology of concrete be deferred until the characteristics of soil-cement become familiar.

Soil-cement in the following discussion is defined as a tightly compacted mixture of pulverized soil, portland cement and water which, as the cement hydrates, forms a hard, durable structural material. Soil, as generally used in connection with the term soil-cement, is defined as the materials in the earth's surface which will vary from gravel to clay and include innumerable combinations, depending upon topography and weather. Another general requirement for soil-cement is that 55 per cent or more of the soil shall pass a No. 4 sieve. (Other materials such as cinders, stone chips, etc., are also used.) However, the "philosophies" of soil-cement covered in this paper pertain particularly to naturally occurring fine-grained soils or soils in which the quantity of minus No. 10 sieve-size material is greater than the voids in the plus No. 10 sieve-size material when compacted. As the quantity of coarse aggregate is increased, a point is reached where concrete technology governs. This transition zone between soil-cement technology based on

fine-grained soils and concrete technology is discussed only briefly in this paper.

In this discussion, soil is considered to be an aggregate. As such it requires pulverizing to permit an intimate mixture of soil and cement. Moisture must be uniformly distributed throughout the mixture in sufficient quantity to hydrate the cement.

The first step taken by the author in the investigation of mixtures of soil and cement was a thorough search of the scientific and technical literature to learn past experiences and uses. A primary objective in the search was to uncover any proportioning or testing procedures that might be helpful. However, the search did not disclose any practical method of fabricating soil-cement specimens for testing to give either interpretable or reproducible results. Consideration was given to testing and evaluating the mixtures as soils using various available American Society for Testing Materials procedures for testing soils. None were applicable because cement characteristics of setting time, hydration, etc., either introduced uncontrollable variables into these tests or produced a mixture not amenable to testing by these procedures.

Moisture-Density Relations of Soil and Soil-Cement

As the literature search was continued and various hypotheses investigated that might be applicable to mixtures of soil and cement, the work on earth dam construction by R. R. Proctor (M. ASCE) of the Los Angeles, California, Water Board was encountered in a series of articles in Engineering News-Record.[1] Mr. Proctor's articles showed that an exact relationship (moisture-density) exists between the moisture content of a pulverized soil and the density to which it can be compacted with a controlled compaction effort. Further, there exists a certain moisture content (optimum) for the pulverized soil which will result in the greatest (maximum) density under the controlled compactive force. The optimum moisture decreases and maximum density increases as the compactive effort increases until further increases in compactive effort are no longer reflected in lower optimum moistures and higher densities.*

It was at once obvious that in case these same relations also existed for soil-cement mixtures before cement hydration it would be possible to make as many identical laboratory specimens as research and testing might require. Also that definite construction methods could be based on these relations to control construction.

The most important practical aspect of the Proctor moisture-density concept was that by compacting soil to maximum density at optimum moisture content, the optimum structural strength and load-carrying capacity of the soil will be attained. Also, as demonstrated by Proctor,[1] the strength of many soils, so consolidated, is high enough to have many practical applications. Hence, if the addition of cement would hold the mass in this condition regardless of moisture changes, a new structural material, having many new uses, would result.

With the concept of moisture-density relations as background, the active investigation of soil-cement by the Portland Cement Association was born.

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*Some time later it was learned that the California Division of Highways, Materials and Research Department, under the direction of T. E. Stanton (M. ASCE) conducted soil compaction tests as early as 1929.

Then followed a selection, with the assistance of the U. S. Bureau of Public Roads, of typical fine-grained soils, 17 in all, occurring in the United States, ranging from sands with little silt and clay content to soils high in clay content and water holding capacity. Research and testing programs were outlined in detail and engineering personnel employed to assist on the laboratory work. Moisture-density tests were made on these dried and pulverized soils after cement was uniformly incorporated. This initial work proved conclusively for the first time that the moisture-density relations of a wide range of soil types were not vitiated by the chemical or physico-chemical action of unhydrated cement. Also that it was a simple and easy matter to prepare mixtures of pulverized soil, various quantities of cement and water and to compact them before cement hydration.

These data supplied an answer to an equally important, fundamental requirement of cement hydration and the successful and practical use of moisture-density control methods. The quantity of contained moisture (optimum) at maximum density was more than adequate to supply all the moisture required by the contained cement* for complete hydration.

The next step in the research program was to evolve test methods for evaluating the influence of various cement contents, moisture contents, and densities on the physical characteristics of compacted mixtures after cement hydration. Since cement hydration would influence final results materially, rate and amount of cement hydration was recognized by permitting specimens to remain undisturbed and untested for 7 days in an atmosphere of high humidity. This would permit hydration of a significant portion of the cement.

Evaluation of Compacted Soil-Cement Mixtures

In analyzing possible test methods that might be used for the evaluation and analysis of compacted and hydrated soil-cement mixtures, soil tests used in soil testing, and strength tests used in concrete testing, were all carefully reviewed and analyzed. The chemical and physical characteristics of soils and of cement as they might influence the relations and reactions of soil and cement were each similarly carefully studied and analyzed.

Since small quantities** of cement were added to the soils in the initial series of tests, and compacted densities varied appreciably, it seemed obvious that the changes produced in the characteristics and properties of soils by cement could be more easily and accurately evaluated than would changes in the cement produced by the soil.

Also, in order for the research work to evaluate cement influence accurately, a basic decision was made to place the same number of cement grains in a unit volume of compacted specimens designed for comparison. This was accomplished by basing cement content design on apparent volume of cement. Thus, all compacted specimens containing 6 per cent cement by volume, for example, had the same number of cement grains present regardless of the density of the specimen. Volume quantities of cement were converted to weight for accurate laboratory fabrication and control.

It is well known that major changes in the physical properties of soils are brought about by changes in moisture content. For example, clay soils when

*The quantity of cement required with normally reacting soils to produce a structural material.

**2 to 8 per cent cement by volume of compacted specimen.

dry have very high structural strength brought about by the cohesion of the clay particles. External compressive forces that might be applied to force the soil grains together could not possibly approach these natural cohesive forces either in magnitude or nature. The phenomenon could be reproduced however by subjecting test specimens to a simple wetting and drying procedure.

Adding moisture to an air-dry clay can introduce expansive forces of the order of several hundred pounds per square inch which might be augmented by subsequent freezing. During absorption of moisture the structural strength of the soil is materially reduced. While it might be hypothesized that a tensile strength test might simulate the forces of moisture and freezing pushing the soil particles apart, it similarly could not possibly approach these natural swelling forces in magnitude or nature. However, these swelling forces might be reproduced and replaced with the expansive forces of freezing water.

These analyses of the forces and factors influencing soil strength and consideration of cement as an admixture gave birth to the idea of developing procedures for subjecting the compacted soil-cement mixtures to alternate wetting and drying in one case and to alternate freezing and thawing in the second case. The influence of cement would then be judged by volume and moisture changes in the specimens and how much, if any, material was lost from the specimens during test.

Hence, the two procedures were selected to reproduce in the laboratory the phenomenon of moisture changes in soils. It was recognized that the wetting and drying procedure, through the use of temperatures above those occurring in nature, would accelerate cement hydration and the influence of the cement in the mixture in a manner not prevailing on construction but that cement hydration acceleration did not exist with the freezing and thawing procedures.* Thus, the two procedures gave critical data on cement hydration required to evaluate reactions of soil and cement.

Factors Governing Tests

Many factors were considered in deciding upon the details of the two test procedures. A review of the ceramics literature revealed that temperatures above about 160° F might bring about chemical and physical changes in the clay and colloidal fraction of a soil so this temperature was selected as a limiting maximum. Also, as previously mentioned, moisture plays a predominant role in the strength of soils and it was essential that water be permitted to play a predominant part in the wet-dry test. This was accomplished by submerging the specimens in water during the wetting cycle. The same principle was applied to the freezing and thawing cycle by placing the specimens on saturated absorbent pads to permit the specimens to absorb moisture during the thawing cycle.

The number of cycles of testing and their duration were carefully considered. Exploratory tests on freezing temperatures, freezing time and rate and soaking time evolved a time cycle for each test. Also, since some time limit was necessary for practical reasons, it was concluded after suitable

*Later, research and field experience revealed that the freeze-thaw test also was most useful in evaluating the surface chemistry of soils, particularly sandy surface soils originating in coniferous tree bearing areas.(2)

exploratory tests that 12 cycles of each test should develop interpretable, reliable data. The preliminary testing and comparisons as well as more than 20 years subsequent experience have substantiated this premise.

The significant data obtained consisted of volume, moisture and weight measurements made at the beginning and during tests. Early in the investigation it was learned that the weight losses were erratic for specimens of the lower cement contents, thus giving most irregular weight loss curves which made analysis of data impossible. This prompted a series of exploratory procedures to overcome this shortcoming from which a brushing procedure was evolved which gave reproducible results.

The establishment of some of these details of test extended over a considerable period of time in some cases and included many exploratory and comparative tests to evolve dependable, reproducible and comparable results.(3)

As a part of the research program, data were obtained on other factors such as soil gradation, surface area and physical test constants, compressive strength, organic content, pH, cement contents, densities, and cement-voids ratio. Involved in this critical study were 329 soils from 37 states.(4) These factors for each soil and soil-cement mixture were studied and compared in a search for relationships which could be used to design the cement content of soil-cement mixtures intended for field use.

These studies of various relationships gave erratic and indeterminate results. However, these supplementary tests did reveal many other significant characteristics of compacted soil-cement mixtures. For example, with some soils, lower cement contents did not improve structural strengths or volume stability appreciably, but, as cement contents were increased, a point is reached where the addition of one or two more percentage points of cement results in substantial increases in structural strengths and volume stability. This point is developed further in the section on CEMENT-MODIFIED SOILS. After this major soil and cement reaction takes place to produce a structural material, a fairly constant relationship between structural strength and cement content was found to exist for a specific soil. Very recent work(5) by the Portland Cement Association Laboratories supplies additional data substantiating these relationships for individual soils.

The previously mentioned wet-dry and freeze-thaw tests did give dependable, reproducible, and interpretable results. They were worked up into final procedures by Committee D-18, Soils for Engineering Purposes, American Society for Testing Materials with the active assistance of a large number of laboratories of State Highway Departments, the U. S. Bureau of Public Roads, various universities, their personnel, and others. These test procedures(6,7,8) were adopted by the Society as "Tentative Standards" in 1940, as "Standards" in 1944, and were brought up to date in 1957.

The development of the first ASTM tentative test procedure for determining the moisture-density relations of soils was completed under the chairmanship of the author in 1942 by a sectional committee of Committee D-18, Soils for Engineering Purposes. Practically all types of earth embankments constructed in the United States are now controlled with specifications based on the basic principles of these relations.

The criteria developed for determining cement contents required to produce a durable, weather-resistant structural material will be discussed later.

Surface Chemistry of Soils

The study and analysis of test data involving the 329 soils previously mentioned[4] clearly revealed that the surface chemistry of the soil was a predominant controlling factor governing the reactions of soil and cement. For example, soils having the same gradation but of differing soil series and horizons had different moisture-density relations, required materially different cement contents to achieve the same hardness and resistance to changes in moisture contents, and possessed varying structural strengths.

The predominant influence of the surface chemistry of soils was first encountered in 1936 on a field project of the Wisconsin State Highway Department.[9] A sandy soil, high in organic content (as determined by the ASTM colorimetric test for sands) did not harden with usual quantities of cement. A laboratory exploratory investigation revealed that the addition of 20 per cent clay from a nearby borrow pit changed the characteristics of the combined soil so that it reacted satisfactorily with about 10 per cent cement.

As a result of these early experiences with soil-cement mixtures, the probable significance of the surface chemistry of soils was recognized in the late '30's. The Portland Cement Association established a fellowship at the University of Missouri under the direction of Dr. Hans F. Winterkorn (M. ASCE) to explore this possibility.[10] A limited number of soils were selected for study, and by a process little known at the time the adsorbed ions on the soil were controlled. Usual soil-cement test procedures and others were then followed to evaluate the influence of the adsorbed ion on soil-cement reactions. The study definitely established the major influence of adsorbed ions but quantitative evaluation proved illusive.

The study of test data on organic content from the 329 soils previously mentioned[4] showed that organic content as determined by the ASTM colorimetric test was not a direct indicator of its influence on cement reaction. The studies did reveal however that some deleterious coating occurred on predominantly sandy surface soils from coniferous tree bearing areas such as encountered on the Wisconsin project and later projects in southeastern states. Studies of this phenomenon relative to surface chemistry were pursued for several years in the laboratory where it was discovered that these unfavorable surface chemistry factors could be overcome by additions of clay or small quantities of calcium chloride.[2]

The evidence of the influence of the surface chemistry of a soil on cement reactions was also recognized from other field experiences and research. The Michigan State Highway Department was a pioneer in recognizing the basic influence of soil forming processes on the physical properties of soils. This pedological approach was used on their first soil-cement project[11] and gave some indication that soil identification by this system might be applicable to some aspects of soil-cement interpretation. Somewhat later, the North Carolina State Highway Department, independently pursued this phase of soil classification and definitely proved that the cement reaction to all soils belonging to the same soil series and horizon was the same even though the soil series and horizon might be separated physically by considerable distance.[12] This same approach was used recently by the Portland Cement Association to evaluate cement requirements for soils involving 42 major soil series occurring in a very large area in the western plains east of the Rocky Mountains.[13]

The foregoing review pointing up the influence of surface chemistry of soils in soil-cement reactions is given in some detail since it is the view of

the author that the next major advance in soil-cement technology will be accomplished by a scientific research program in this area. Also, this possible advance may contribute materially to the chemistry of cement and accordingly, concrete technology.

It is recognized that the wet-dry and freeze-thaw tests are somewhat time consuming. However, as is true in all testing, the governing criteria of a test procedure is its dependability and reproducibility. In this respect the wet-dry and freeze-thaw tests have an excellent record. Projects are giving fine field performance on which cement contents for construction were determined by this procedure and moisture, density, and cement content were properly controlled during construction. This record includes the first scientifically controlled project,[14] 1.5 miles long, built at Johnsonville, S. C., in 1935 by the South Carolina State Highway Department in cooperation with the U. S. Bureau of Public Roads and the Portland Cement Association through to the end of 1957 when total soil-cement paving in the United States exceeded 200,000,000 sq. yds. All this paving, except a fraction of one per cent, is giving dependable service with a minimum of maintenance. That fraction of a per cent mentioned includes replacements with higher type pavement, roadway abandonment and limited areas not meeting construction specifications. It is a service record without equal in the low-cost paving field.

Determining Cement Required for Construction

As noted, it was necessary to establish criteria for determining cement contents required to produce a hardened structural material for use on paving construction to insure durability and long life. The following theories and principles governing the characteristics of fine-grained soils and of cement

Conducting moisture tests for moisture-density control of compaction on the Johnsonville, S. C. soil-cement project. It is believed that this was the pioneering use of these procedures on base stabilization road work.

emerged as also significantly governing the quality of compacted soil-cement mixtures.

Returning to an earlier statement that a strong, usable construction material would be produced if cement would hold the mixture at optimum moisture and maximum density, it becomes clear that this can be judged in part by measuring changes in moisture content and density of compacted mixtures during the wet-dry and the freeze-thaw test. If the specimens do not undergo material volume change (in terms of soil volume changes) during these tests they have not changed density materially. Further, if the volume of the moisture contained in the specimens at the conclusion of the tests does not exceed total air voids at time of compaction, additional evidence is supplied that densities have not changed materially. Equally important is the correlated evidence that the expansion forces inherent in the soil that are induced by absorbed moisture and by the expansion forces induced by freezing water are resisted and controlled by the physical and chemical characteristics of the cement to prevent the soil grains from separating. Natural shrinkage forces induced by drying, and which may be of major magnitude, are similarly controlled. Applying these hypotheses rigorously to all phases of the wet-dry test and the freeze-thaw test results and to the previously mentioned exploratory research work[3,4] clearly established their validity.

It was also necessary to consider principles governing cement and cement hydration. One of the most important factors established in concrete research and experience is the fact that concrete continues to increase in strength with age and additional cement hydration provided it is not exposed to physical or chemical factors (such as weather or aggressive waters) which will induce deterioration. Also, the physical strength of concrete increases with increases in cement content, all other factors being equal. Consideration of these cement and concrete characteristics led to establishing a further criteria for judging a structural material that the physical strength of compacted

The initial use at Johnsonville, S. C. of sheepsfoot rollers in conjunction with Proctor moisture-density control on base stabilization road work.

soil-cement mixtures should increase with increases in cement content and with age. The data previously mentioned[3,4] support these hypotheses.

The foregoing considerations and analysis of test data established the following criteria for judging cement reaction and for determining cement requirements for a hardened structural material for paving:

a) Maximum volume at any time during either wet-dry test or freeze-thaw test shall not exceed volume at time of molding by more than 2 per cent.*

b) Maximum moisture content at any time during either wet-dry test or freeze-thaw test shall not exceed that quantity which will completely fill the voids of the specimen at time of molding.**

c) Compressive strengths of soil-cement test specimens, soaked in water 1 to 4 hours prior to test,*** shall increase with age and with increases in cement content in the ranges of cement content producing results meeting requirements a) and b) above and a third criteria, d), regarding soil-cement losses which will be discussed next.

It was considered necessary also to give recognition to the quantity of material lost during the wet-dry and freeze-thaw test even though the technique established for handling the specimens involved in this series of tests was a practical evolution of the problems involved. In case the cement was holding the soil particles together effectively (to maintain the molded density), the amount of material loosened during the cycles of wetting-drying and freezing-thawing must of necessity be quite low. Equally obvious was the fact that the brushing technique was of such a nature (forcefulness) that more material would be removed from very sandy, rough textured specimens than from clayey, smooth textured specimens. Hence, soil-cement losses of specimens having similar physical characteristics would have different material losses during these repeated cycles with the sandy soils having the higher material losses.

In the early work, as laboratory test data was being accumulated which included outdoor exposure of laboratory test specimens and the study of the performance of field construction, an arbitrary soil-cement loss figure was applied that was quite low. With the accumulation of extensive data, particularly field performance data on the projects built in all parts of the United States and some areas of Canada, it was possible to establish governing criteria that were a direct evaluation of the structural stability of compacted soil-cement mixtures in service. The criteria used are as follows:

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*This criteria is of particular interest on research work. Experience indicates that it is not a governing factor with most soils occurring in the United States so that its use is generally optional for other work. However, an occasional soil may possess characteristics which produce changes making this item critical.

**This criteria is of particular interest on research work. Experience indicates that it is not a governing factor with most soils occurring in the United States so that its use is generally optional for other work. However, an occasional soil may possess characteristics which produce changes making this item critical.

***To assist in releasing any cohesive forces introduced by the clay component of the mixture.

d) Soil-cement losses during 12 cycles of either the wet-dry or freeze-thaw test shall conform to the following standards:

Soil Groups* A-1-a, A-1-b, A-3, A-2-4 and A-2-5, not over 14 per cent
Soil Groups A-2-6, A-2-7, A-4 and A-5, not over 10 per cent
Soil Groups A-6, A-7-5, and A-7-6, not over 7 per cent

Thus, to produce a satisfactory structural material, the field performance of projects and field exposure of test specimens were correlated with laboratory results of soil-cement losses during test. Reinforced by more than 20 years' experience, field projects, built with cement contents selected according to these criteria, demonstrate that a structural material is produced with excellent durability and resistance to weathering. Cement contents have varied from about 6 per cent to 16 per cent by volume with cement contents of 8 to 12 per cent by volume governing construction for a wide range of soil characteristics and gradation.

Further explanation of the reasons for selecting these criteria for general use rather than a strength test is desirable. The accumulated compressive strength data[4] showed clearly that the selection of a particular minimum compressive strength value to give a cement content that would produce a satisfactory structural material of the very wide range of soils occurring in this country would be materially higher than that required to give satisfactory results for most soils. This would in turn materially increase construction costs (cement constitutes about one-half the total cost of construction) and would defeat one of the primary needs of this type of work, namely, low cost.

However, compressive strength data can be a valuable tool for analyzing cement requirements and physical characteristics of compacted soil-cement. As previously mentioned, once the cement required to produce a structural material from a specific soil (pedologically identified) has been established and the resulting compressive strength determined, further testing of this same soil may be based on the previously determined compressive strength.[12,13] Also, strength analysis may be used for judging compacted mixtures containing this soil and greater cement contents.[5] Further optional short-cut laboratory test procedures based on compressive strength have been evolved to analyze cement requirements for sandy and granular soils.[15]

Construction Control

At the same time research was in progress which revealed some of the basic principles governing soil-cement mixtures, research was conducted to determine basic construction control factors. In addition to the basic control of the moisture content, density and cement content, it was necessary to learn the degree of soil pulverization required, time limits for adding moisture and for compacting the mixture and other construction factors.[16] Testing and field experience developed the following factors for soil-cement in general:

Maximum size aggregate—3 inches.
(Correlated with sheepsfoot roller sizes)

55 per cent or more pass the No. 4 sieve. (To give sufficient fines to encompass the coarse fraction)

*U. S. Bureau of Public Roads Classification.

Pulverize until 80 per cent of the soil, exclusive of gravel or stone retained on a No. 4 sieve, by dry weight, passes a No. 4 sieve. (To give intimate mixture of soil grains and cement)

Restrict addition of cement when moisture content of soil exceeds optimum. (To permit efficient mixing and eliminate cement balls)

During cement mixing operations, mixture shall be agitated at least once every 30 minutes until compaction begins. (Cement hydration factor)

All moisture must be added to a construction section in less than three hours. (Cement hydration factor)

Compaction must be completed within two hours. (Cement hydration factor)

Time lapse between spreading of cement until compaction is completed shall not exceed six hours. (Cement hydration factor)

Moisture content at time of compaction shall not be below nor more than one-fifth above the specified optimum. (To insure adequate moisture and density)

Density obtained must not be less than 5 lbs below the specified maximum density. (To insure adequate density control. Excess density is beneficial.)

A suitable cover of moist hay, straw, or earth, or a light bituminous seal must be placed on the completed work to prevent evaporation of surface moisture for about seven days and thus permit proper hydration of the cement in the surface and produce corresponding hardness.

Place a bituminous surface on the completed work commensurate with traffic requirements. As traffic volume and weight increase, the thickness and quality of the bituminous surface is increased.

The engineering press has published a considerable number of articles describing equipment, and construction operations and costs on road, street, and airport runway soil-cement paving. This area of interest is beyond the scope of this paper and will not be covered.

Cement-Modified Soils

Along with the development of soil-cement for paving, came an equally interesting and valuable use of cement as a soil admixture to modify the physical characteristics of fine-grained soils of high water holding capacity and volume change characteristics. Soils having these characteristics may cause excessive distortion of pavements and have low supporting values as their moisture contents vary with weather conditions.

In 1936 the Kansas State Highway Commission conducted research on expansive soils and built a test road to evaluate methods of reducing subgrade volume changes. Included were sections containing cement as an admixture and built in the same manner as compacted soil-cement.[17] Shortly afterward the Oklahoma State Highway Commission built an extensive section of

cement-modified soil to produce satisfactory volume stability in a heavy clay subgrade for a concrete pavement.[18]

Laboratory tests[16] conducted in connection with this work with cement-modified soil clearly demonstrated that the grains of cement served as a nucleus to which the fine soil particles adhered. Thus, the quantity of clay and silt was progressively reduced as cement was added to produce a coarser grained soil of lower water holding capacity and increased volume stability and supporting value. Thus, as more and more cement is added, the quantity of coarse grained soil increases until the point is reached where all the soil grains coalesce into a solid mass to produce a structural material.

In an analysis of test data obtained in connection with field projects[17,18] it was found that about two days hydration of cement in a compacted mixture produced a major influence. Also, that hydration continued and the agglomeration of fine soil grains and cement was of a long-range character and not temporary. The basic principles of soil characteristics, the foregoing test data, and successful field experience have demonstrated that a low volume change soil can be produced by using sufficient cement to reduce the plastic index of the soil to about 10 and to change the shrinkage limit and liquid limit of the mixture so that the ratio of the volume at the shrinkage limit to the volume at the liquid limit is more than 0.80.

This same approach to soil modification with cement is used effectively with mechanical (granular) stabilization when the clay fraction quantity exceeds allowable limits or has excessive water-holding capacity or the material has deficient bearing values or strength. Cement is added in sufficient quantity to overcome these shortcomings.

The California Division of Highways has pioneered and developed to a high degree of perfection the use of cement to improve substandard granular materials. Cement treatments range from small cement additions to larger quantities to produce hardened soil-cement. Their use of the latter type of treatment as a subbase for concrete paving in conjunction with sawed joints has resulted in new high concrete pavement performance standards. Construction procedures follow those used for soil-cement paving by controlling moisture, density, cement content, etc.

Plastic Soil-Cement

A third use of soil-cement mixtures involves structures such as low-cost irrigation canal linings, ditch and reservoir linings, etc., where usual mixing and compaction equipment cannot operate because of steep slopes or lack of space. In such situations it would be possible to place premixed soil-cement of the consistency of masonry mortar and to finish it with screeds similar to those used for concrete. Such a mixture would have a moisture content above "optimum" and density below "maximum" density.

Research work to determine construction control factors evolved rather simple but effective test procedures. Plastic soil-cement mixtures were produced in the laboratory which had the placement characteristics suitable to intended use. It was obvious from knowledge obtained with compacted soil-cement that cement contents would be increased because of increased voids (reduced density). Cement contents for test were selected accordingly. The resulting specimens were tested by the previously mentioned procedures together with the previously cited criteria for selecting cement contents for pavement construction.

In general, plastic soil-cement mixtures require about 4 percentage points more cement than compacted mixtures to meet the same criteria. Construction control is then based on the characteristics of the plastic mixture meeting construction requirements and consists of its moisture content, density, and cement contents. An excellent example of required testing and construction operations was supplied by an experimental low-cost irrigation canal lining built at Altus, Oklahoma by the U. S. Bureau of Reclamation in 1947.(19)

A detail discussion of the several field uses of soil-cement are covered in a paper, "Soil-Cement: A Construction Material," presented at a "Conference on Soil Stabilization" held at Massachusetts Institute of Technology in June, 1952, and will not be repeated here.(20)

SUMMARY

This discussion of soil-cement has concentrated on the interpretation and citation of research and development work on fine-grained soils. Compacted soil-cement is a unique structural material having its own structural characteristics which are influenced primarily by the surface chemistry of soils. It is a low-cost material because the soil on or near the site is used as aggregate thus eliminating the cost of importing aggregates. Further, a narrow range of cement contents covers wide ranges in soil gradation and characteristics. A study of the cited research and test data, which is not included in this presentation for lack of space, will give the factual information needed to specifically evaluate soil-cement mixtures.

At present it appears that research on the surface chemistry of soils and its influence on cement reaction will supply data needed for further advances in the science of soil-cement relations. However, in the meantime, presently used testing and evaluation methods supply dependable, reproducible and practical controls for the several low-cost structural applications of soil-cement mixtures.

ACKNOWLEDGMENT

The author is deeply indebted to the late Frank T. Sheets (M. ASCE) while Director of Development, and, later, President of the Portland Cement Association, for his continued encouragement, and for his enthusiastic support of the Portland Cement Association soil-cement programs directed or supervised in part by the author.(2,3,4,9,10,11,14,16,17,18,19) This support was particularly valuable in the early years of the work when past practice and experience with concrete discouraged the idea that cement could be successfully mixed with soil to produce a dependable construction material. Also, the author acknowledges the sincere and energetic assistance, particularly during the early, decisive period of the laboratory investigation, of his associates, E. J. Felt (M. ASCE)*, J. A. Leadabrand (M. ASCE),** L. T. Norling (Assoc. M. ASCE),† E. G. Robbins (Assoc. M. ASCE),†† and of numerous

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other engineering members of the staff who assisted on laboratory and field projects, of Highway Department personnel, especially those who authorized the pioneering field projects and assisted in their construction, and of many, many others. The successful prosecution of the work during the development years would have been impossible without their help.

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HIGHWAY-TRAFFIC ESTIMATION BY LINEAR PROGRAMMING

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The large highway construction program which is being initiated this year is presenting many problems. Among these are the problems associated with traffic estimation for design purposes. In the past traffic estimation was not considered as important as it is today. With the limited access highways of today, traffic estimation has become an important function which must be performed as a prerequisite to design.

This article demonstrates the general method by which linear programming may be applied to traffic estimation relating to interchange design. By further study this general method could doubtlessly be improved and applied to other traffic problems.

The location chosen for this study was the proposed interchange of the Federal Aid Interstate Route (F.A.I.) 03 with U S 50 near Seymour, Indiana. F.A.I. 03 is a proposed limited access highway which at this point parallels U S 31 on the east. The reasons for choosing this particular location were the availability of data and the relative simplicity in the pattern of highways in the surrounding area.

Thus, the problem was conceived in the following fashion: To enable the design of an interchange at the crossing of a proposed interstate route and a major crossing route, it was necessary to estimate the flow of traffic on the interstate route and the crossing route on both sides of the interchange and to use these estimates to arrive at the traffic flow on the interchange itself.

The first half of the problem was taken as given in this analysis. That is, the traffic flow on the interstate route on either side of the interchange and the traffic flow on the crossing route, on the side of the interchange opposite the existing, parallel route, was taken as given. This seemed to be in keeping with present traffic estimation procedures, in which an estimate of the traffic volumes between interchanges is made for a proposed limited access highway, before attempting to estimate traffic on the interchanges proper. The volume of traffic on the crossing route, on the side of the interchange opposite the existing, parallel route, was assumed to be unaffected by the proposed interstate route and was found by an automatic counter placed at the location. Therefore, the only estimate of traffic flow into the interchange that was

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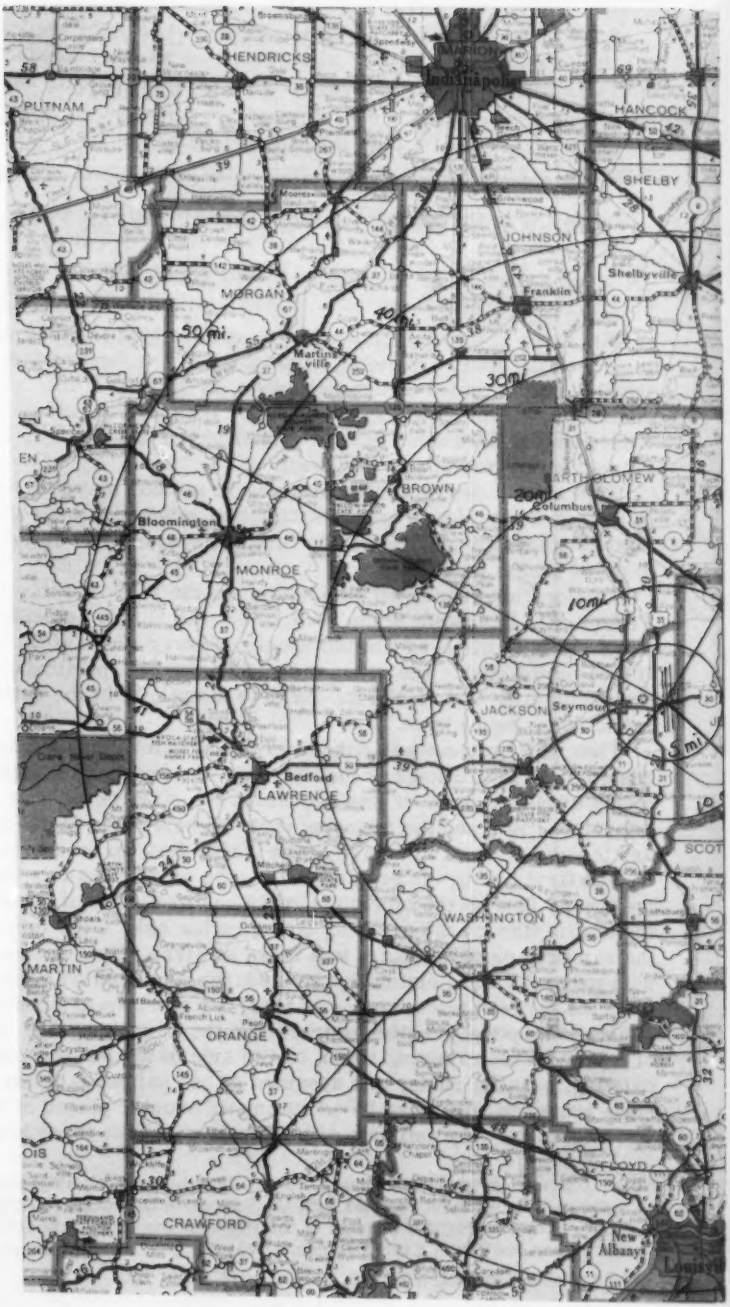
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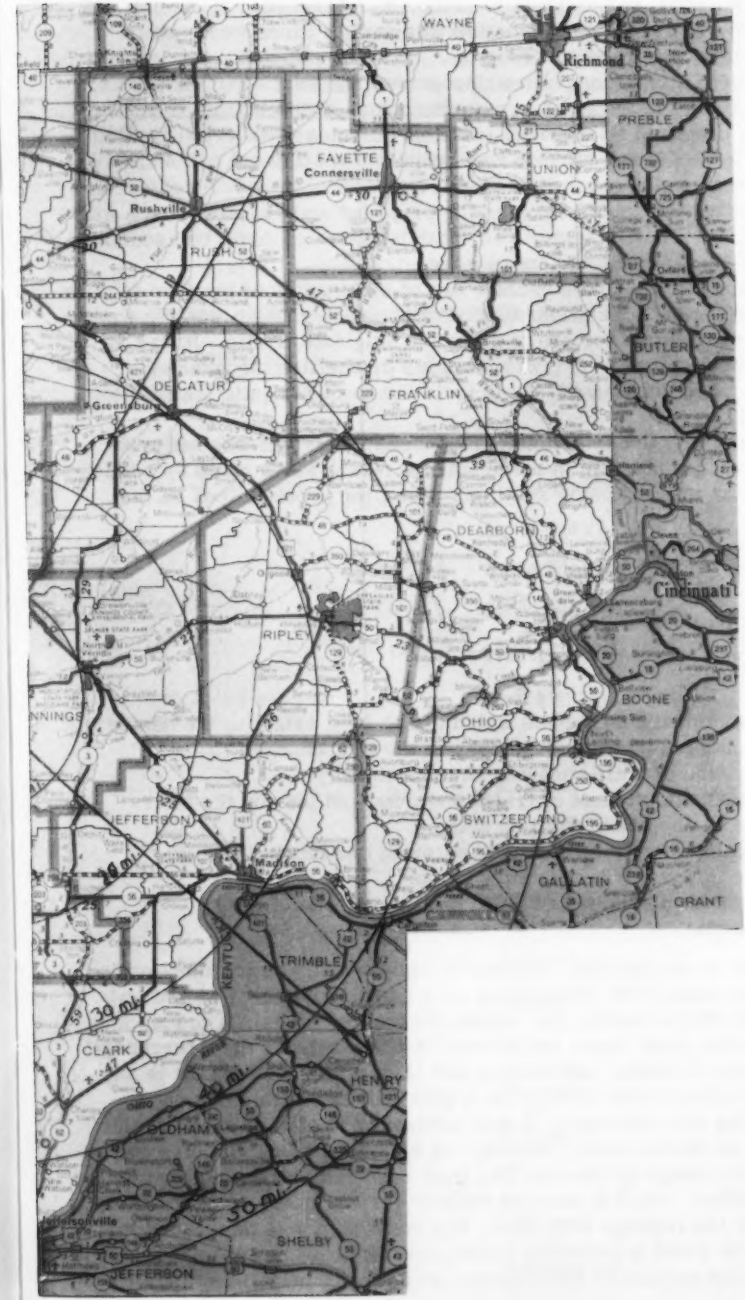
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required in this model was the flow on the crossing route between the interchange and the existing, parallel route. Thus, it is seen, the approach to the problem of traffic estimation presented in this article presupposes some initial estimation by standard procedures.

The first step in attempting a linear programming solution to the problem of traffic estimation was to obtain a map showing an area of 50 mile radius surrounding the proposed interchange location. Circles were drawn on this map at 5, 10, 20, 30, 40, and 50 mile radii with the interchange in question at the center. These circles were divided into four approximately equal sectors by roughly bisecting the angles between the proposed and crossing roads with lines. (See Fig. 1). Thus, a sector was established which could be associated with each of the four interchange approaches.

The immediate objective then became one of making use of the four sectors and their corresponding populations to arrive at a factor which would measure the ability of each of these sectors to draw and originate traffic. It was intended to use these factors to arrive at weights or coefficients in an expression which, when maximized, would yield the most realistic traffic flow on the interchange.

Before entering into the determination of these factors, it was believed pertinent to set the problem up in mathematical terms which could be related directly to a linear programming solution. Thus, the problem took on the following form:

$$\text{Maximize} \quad \sum_j c_j \cdot x_j \qquad j = 1,\dots 6$$

$$\text{Subject to:} \quad \sum_j x_j \leq b_i \qquad i = 1,\dots 4$$

$$\sum_j x_j \geq f_i \qquad j = 1,\dots 6$$

$$x_j \geq d_j$$

where c_j = the functional coefficients which are to give weight to the desire for making a traffic movement j in the interchange.

x_j = the volume of traffic making any movement j

b_i = the maximum volume of traffic entering and leaving the interchange in any one of the i directions.

f_i = the minimum volume of traffic entering and leaving the interchange in any one of the i directions.

d_j = the minimum volume of traffic making any one of the i movements.

The expression to be maximized, referred to subsequently as the functional, was seen to be the sum of the products of each traffic movement weight (c_j) and the volume of traffic making the respective movement (x_j). The constraints, on the other hand, were established by the nature of the interchange. That is, the volume of traffic approaching and leaving the interchange in any direction must be equal to the sum of the traffic movement volumes on the interchange serving this approach. It was necessary to state this constraint in two equations, as shown above, because one of the approach volumes was stated in terms of a range of values. The final constraint was added to give reality to the solution. Since it seemed unlikely for any of the possible traffic movements on the interchange to be zero, this constraint was introduced to provide a means by which a minimum traffic volume could be set up for each movement. For this particular interchange, an estimate of minimum traffic

volume was made for only three of the six possible movements; namely, the three movements associated with the smaller functional coefficients.

Having written the problem in mathematical terms, it was possible to proceed in the determination of the functional coefficients; i.e. the c_j terms. The first step in this direction was to obtain the population of the townships within a ten mile radius of the interchange and city populations over one thousand within fifty miles of the interchange. (See Tables I and II). Subsequently, in Table II, the township populations were broken down by sectors as established previously for this road pattern. (See map)

Table I

Cities Surrounding Intersection of FAI 03. With U S 50 East of Seymour, Indiana, Sub-divided by Distance From This Intersection.

Location	City	Population *
0 - 5 mi.	Seymour	8620
5-- 10 mi.		
10 - 20 mi.	North Vernon	3112
	Scottsbury	2189
	Crothersville	1169
	Browstown	1860
	Columbus	11,738
20 - 30 mi.	Madison	6923
	Salem	3194
	Edinburg	2466
30 - 40 mi.	Franklin	6264
	Shelbyville	10,791
	Greensburg	6065
	Batesville	3065
	Osgood	1198
	Milan	1000
	Orleans	1428
	Mitchell	3393
	Bedford	12,514
	Oolitic	1186
	Bloomington	20,870

Table I (cont.)

Location	City	Population *
40 - 50 mi.	Rushville	5960
	Louisville	319,077
	Jeffersonville	11,493
	New Albany	25,414
	Martinsville	5009
	Indianapolis (50 mi)	386,972
	Cincinnati (70 mi)	455,610

* All population figures are from the 1940 census.

It was found necessary to record the city populations in the proper sector and to arrive at a means to relate the ability of each of these population centers to create traffic on the interchange in question. It was decided to approximate each center's ability to create traffic on the interchange by the ratio of the population divided by the square of the distance from the population center to the interchange. Thus, taking the population centers in each sector and dividing by the square of the distance to each center from the interchange, it was possible to calculate a draw factor for each sector. (See Table III)

Due to the limited access nature of the interstate route, it was found impossible for traffic originating or terminating at points along the route, to use the system, unless the point of origin or termination was as far as the next interchange. Therefore, it was necessary to eliminate the population associated with this area from the calculation made in Table III. Of course, on the crossing road no such limited access condition was proposed to exist and all of the population centers shown in Tables I and II was included in Table III.

It should be pointed out, in the light of Table III, that judgment will not be eliminated by the use of linear programming to solve this traffic problem. Rather, it is possible to use the required judgment to set the problem up in a form, from which a solution is obtained by following a set of rules. This article was written to provide a procedure for applying judgment to those considerations requiring it, rather than to formulate the author's judgment. Accordingly, the formulation of such expressions as the ratio for calculating the draw factor of each population center was meant to be very flexible and was chosen in this analysis as a simplified approximation to the true relationship which exists. Therefore, the accuracy of any solution can probably be improved by introducing addition considerations in applying judgment to the problem. These addition considerations increase the time and cost involved in such a solution, so must be weighed against the increase in accuracy of the solution.

Continuing with the analysis, the method to obtain the draw factor associated with each of the four sectors was shown in Table III. Then, it became

Table II

Breakdown of Township Areas Within a 10 Mile Radius of the Intersection of FAI 03 With U S 50 by Sectors.

County[1]	Township[2]	% within[3] 10 mi.	% in[4] Sector	Sector[5] Designation	Sector[6] Pop.**	Total[7] Pop. *
Bartholomew	Wayne	30	100	FAI03 N	500	1592
Jennings	Geneva	40	60	US 50 E	300	1324
			40	FAI03 N	200	
	Spencer	100	10	FAI03 S	100	1123
			90	US 50 E	1000	
	Marion	30	100	FAI03 S	200	675
	Lovett	20	100	US 50 E	100	565
	Vernon	10	100	US 50 E	100	1209
Jackson	Washington	90	70	FAI03 S	500	738
			30	US 50 W	200	
	Vernon	30	100	FAI03 S	300	1100
	Brownstown	20	100	US 50 W	300	1600
	Jackson	100	50	US 50 W	900	1775
			50	FAI03 S	900	
	Hamilton	80	100	US 50 W	1200	1443
	Redding	100	10	US 50 E	200	1607
			20	US 50 W	300	
			70	FAI03 N	1100	

* All population figures are from the 1940 census.

** Column 3 x Column 4 x Column 7 rounded to the nearest 100 persons.

possible to calculate the functional coefficients; that is, the weight to be applied to each traffic movement on the interchange. Following existing procedures for solving traffic estimation problems, a traffic movement was taken to be the sum of the flow from any point on the periphery of the interchange to any other point on the periphery of the interchange and from the latter to the former. Taking this two-way flow as one movement, it became apparent a total of six possible movements existed on the interchange. By taking the draw factor on each movement to be equal to the draw factor on the associated approach roads, a set of draw factors for each movement was obtained. (See Table IV) In other words, by applying each approach road draw factor to each

Table III

Determination of Draw Factors For the Area Surrounding the Intersection of FAI03 With US 50 Just E. of Seymour, Indiana

	Town or Township	Population*	÷ Distance^2	= Draw Factor
FAI03 N				
10-20 mi.	Columbus (town)	11,700	15^2	52
20-30 mi.	Edinburg (town)	2,500	25^2	4
30-40 mi.	Bloominton (town)	20,900		
	Franklin (town)	6,300		
	Shelbyville (town)	10,800		
		38,000	35^2	31
40-50 mi.	Martinsville(town)	5,000	45^2	2
50 mi.	Indianapolis	387,000	55^2	127
Total				216
FAI 03 S				
10-2- mi.	Crothersville (town)	1,200		
	Scottsburg (town)	2,200		
		3,400	15^2	15
20-30 mi.	Salem (town)	3,200	25^2	5
40-50 mi.	Louisville (town)	319,100		
	Jeffersonville(town)	11,500		
	New Albany (town)	25,400		
		356,000	45^2	175
Total				195

of the three possible traffic movement in the interchange from this approach, it was possible to obtain a set of draw factors associated with each movement. The functional weights or coefficients were obtained by summing these draw factors and dividing by ten.

The sketch which follows shows the functional coefficients calculated in Table IV. Also shown on the sketch are the approach road volumes which, with the exception of the west approach, was obtained from the Indiana State Highway Commission.

A range estimate of the traffic volume on the west approach of the crossing route was made in conjunction with this analysis.

Table III (cont.)

	Town or Township		Population* ÷ Distance^2	Draw Factor
US 50 E.				
0-10 mi.	Geneva		300	
	Spencer		1000	
	Lovett		100	
	Vernon		100	
	Redding		200	
			1700 5^2	68
10-20 mi.	North Vernon	(town)	3100 15^2	14
20-30 mi.	Madison	(town)	6900 25^2	11
30-40 mi.	Milan	(town)	1000	
	Osgood	(town)	1200	
	Batesville	(town)	3100	
	Greensburg	(town)	6100	
			21,400 35^2	18
40-50 mi.	Rushville	(town)	6,000 45^2	3
50 mi.	Cincinnati	(town)	455,610 70^2	93
Total				207

It was indicated earlier in this article it was believed more realistic to make an estimate of the minimum volume on the three movements with the lower functional coefficients, than to allow two of these movements to take on zero values due to the nature of the equations. This was done in conjunction with the rewriting of the functional equation and the constraints in a more specific form. These expressions appear as follows:

Maximize $63 x_1 + 14 x_2 + 40 x_3 + 47 x_4 + 41 x_5 + 69 x_6$

Subject to:

$$x_1 + x_2 + x_5 = 4140 \quad (1)$$

$$x_2 + x_3 + x_6 = 6240 \quad (2)$$

$$x_3 + x_4 + x_5 = 4680 \quad (3)$$

$$x_1 + x_4 + x_6 \geq 6000 \quad (4)$$

$$x_1 + x_4 + x_6 \leq 8000 \quad (5)$$

Table III (cont.)

	Town or Township	Population*	÷ Distance^2	= Draw Factor
US 50 W				
0-10 mi.	Seymour (town)	8600		
	Washington	200		
	Brownstown	300		
	Jackson	900		
	Hamilton	1200		
	Redding	300		
		11,500	5^2	460
10-20 mi.	Brownstown (town)	1,900	15^2	8
30-40 mi.	Orleans	1,400		
	Mitchell	3,400		
	Bedford	12,500		
	Oolitic	1,200		
		18,500	35^2	15
Total				483

* Population figures from Tables I & II

$$x_2 \geq 200 \quad (6)$$

$$x_1 + x_5 \leq 3940 \quad (7)$$

$$x_3 + x_6 \leq 6040 \quad (8)$$

$$x_3 \geq 300 \quad (9)$$

$$x_4 + x_5 \leq 4380 \quad (10)$$

$$x_2 + x_6 \leq 5940 \quad (11)$$

$$x_5 \geq 1500 \quad (12)$$

$$x_1 + x_2 \leq 2640 \quad (13)$$

$$x_3 + x_4 \leq 3180 \quad (14)$$

The first five constraints were written from the traffic volumes on the approach roads. Constraints (6), (9), and (12) represent an estimate of the minimum traffic flow on the three traffic movements with the smaller functional coefficients. The two constraints which follow each of these minimum volume

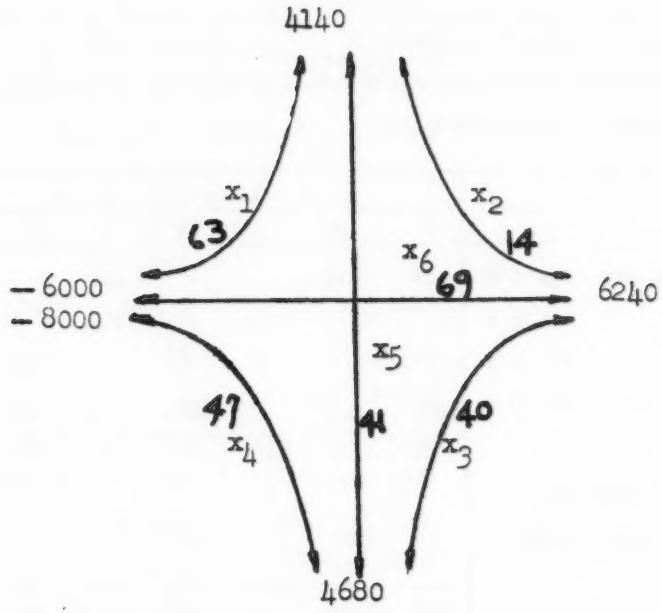
Table IV

Determination of Functional Coefficients from Draw Factors for Interchange of FAI 03 with US 50.

	Movement Designation					
	1	2	3	4	5	6
Draw Factors: FAI 03 N	216	216			216	
FAI 03 S			195	195	195	
US 50 E	207			207		207
US 50 W	483	—	—	483	—	483
	699	423	402	678	411	690
Special reductions * due to layout of the road network	70	283		213		
	629	140	402	465	411	690
Coefficients: Divide by 10 & round off.	63	14	40	47	41	69

* These reductions come about because of the layout of the road network which permits shortcuts across a right angle. For example: The special reduction in Quadrant # 4 (SW) was made because of the shortcut provided by S R 250 or S R 256. The figure 213 was obtained by taking the draw factors on both roads approaching the interchange, caused by population further from the interchange than the intersection of the shortcut with the approach roads, and summing these draw factors.

The reductions in Quadrants # 1 & # 2 contain a judgement factor on the amount of transfer of traffic to the shortcut.



estimates (e.g. (7) and (8)) was found by substituting each of the minimum volume estimates into the appropriate constraints among the first five. Thus, fourteen equations was found sufficient to handle the problem.

To put these equations in a form similar to a linear programming tableau, it was necessary to add additional variables to the constraints stated as inequalities. These slack vectors, so called because they take up the slack in the inequalities, were added as shown below.

Constraints on the Seymour Interchange:

$$x_1 + x_2 + x_5 = 4140 \quad (1)$$

$$x_2 + x_3 + x_6 = 6240 \quad (2)$$

$$x_3 + x_4 + x_5 = 4680 \quad (3)$$

$$x_1 + x_4 + x_6 - x_7 = 6000 \quad (4)$$

$$x_1 + x_4 + x_6 + x_8 = 8000 \quad (5)$$

$$x_2 - x_9 = 200 \quad (6)$$

$$x_1 + x_5 + x_9 = 3940 \quad (7)$$

$$x_3 + x_6 + x_9 = 6040 \quad (8)$$

$$x_3 - x_{10} = 300 \quad (9)$$

$$x_4 + x_5 + x_{10} = 4380 \quad (10)$$

$$x_2 + x_6 + x_{10} = 5940 \quad (11)$$

$$x_5 - x_{11} = 1500 \quad (12)$$

$$x_1 + x_2 + x_{11} = 2640 \quad (13)$$

$$x_3 + x_4 + x_{11} = 3180 \quad (14)$$

Having written the above equations, it was possible to write the constraints in the tableau shown below. The functional coefficients appear in the first row (c_j row) followed by the coefficients on each of the vectors appearing in the constraints in subsequent rows. The right hand side of the above equations was placed opposite the appropriate left hand coefficients in the Po column. To avoid a complex appearance, the zeroes were omitted in the body of the tableau. Thus, the blank spaces are, in actuality, zeroes. The final column in the tableau, C_i, was incorporated to record the functional coefficients from the C_j row associated with the vectors in the solution. Accordingly, no vector with a non-zero functional coefficient was in the solution in the first tableau.

First Tableau (Seymour Interchange)

x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	Po	c_j/c_i
63	14	40	47	41	69	0	0	0	0	0		
1	1			1							4140	0
	1	1			1						6240	0
		1	1	1							4680	0
1			1		1	-1					6000	0
1			1		1		1				8000	0
	1							-1			200	0
1				1			1				3140	0
		1		1			1				6040	0
		1						-1			300	0
			1	1					1		4380	0
	1				1				1		5940	0
				1						-1	1500	0
1	1									1	2640	0
		1	1							1	3180	0

Before going directly to a solution, it was believed helpful to give some of the basic procedures for obtaining a solution by linear programming given the above tableau. As the first step toward a solution, maximizing the desire function subject to a set of constraints, it was necessary to calculate an additional row designated as the "$Z_j - C_j$" row. This row, shown below for the first tableau, was calculated by subtracting the functional coefficient for each vector from the sum of the products of the vector coefficients and the c_i's.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	Po
$Z_j - C_j$ row	-63	-14	-40	-47	-41	-69	0	0	0	0	0	0

The basic procedure, having calculated the "$Z_j - C_j$" row, was to bring the vector into the solution which showed the most negative value in the "$Z_j - C_j$" row. Then, after obtaining a new tableau with the new vector in the solution,

a new "$Z_j - C_j$" row was calculated and the vector with the most negative value was again brought into the solution. This procedure was continued until the "$Z_j - C_j$" row became non-negative throughout; at which time the functional was maximized.

This procedure, of course, hinges on the method for bringing a vector into the solution once it is selected by the above technique. Since it is not the purpose of this article to give a treatise on linear programming,[2] the method for bringing a vector into the solution will not be explained in detail. In essence, the procedure was to choose a key cell in the predetermined column by comparing the rows on the basis of the quotient of Po divided by each entry in the predetermined column; choosing the row with the smallest quotient. After obtaining the key cell, it was necessary to eliminate all other entries in the key column by performing the necessary addition or subtraction of rows. Once the key cell entry was unity and was the only entry in the key column, the new vector had come into the solution at the value indicated in the Po column in the key row.

As mentioned above, this short description of linear programming methods was not intended to equip the reader to verify the results of this analysis. Rather, its purpose was to clarify in the mind of the reader the basic procedure followed in obtaining a solution. Thus, with this background the problem may be pursued to completion.

It was believed unnecessary to include in this article the intermediate tableaux which were calculated by the procedures just given. Accordingly, the

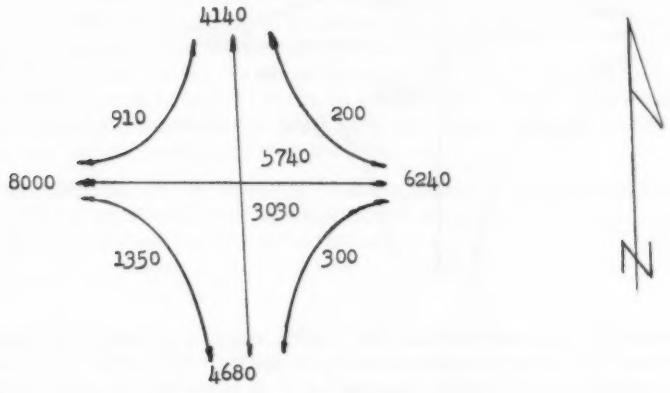
Final Tableau (Seymour Interchange)

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	Po	c_j/a_{ij}
	63	14	40	47	41	69	0	0	0	0	0		
		1							-1			200	14
												0	0
	1							1/2		-1		910	63
							1	1				2000	0
												0	0
								1/2	1	1	1	1530	0
			1							-1		300	40
												0	0
				1				1/2	-1			1350	47
						1			1	1		5740	69
					1			-1/2	1	1		3030	41
												0	0
												0	0
$z_j - c_j$	0	0	0	0	0	0	0	34½	49	7	0	655,870	

final tableau (given above) was obtained after a number of intermediate steps. Following reasoning presented earlier, the functional was seen to be maximized as witnessed by the positive $Z_j - C_j$ row. Therefore, at this stage, it became necessary only to interpret the final tableau and to read off the results.

2. See: Charnes, A., Cooper, W. W., Henderson, A., "An Introduction to Linear Programming."

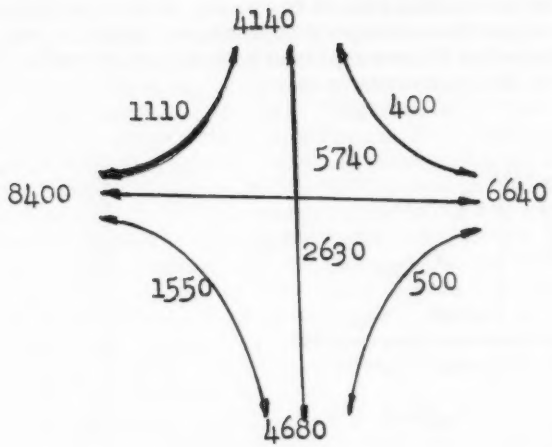
The results were taken off the final tableau by reading the solution to each vector in the Po column in the row corresponding to the unit entry for each vector. Thus, the solution which follows represents the maximum evaluation of the functional subject to the constraints as stated.



In many applications of linear programming it is possible to obtain a considerable amount of information from the value of the maximized functional and the slack vectors. In the model presented herein, it was found the actual value of the functional had little significance. It merely indicated the value of the total desire function for all traffic expected to use the interchange was at its maximum. The slack vectors, x_7 and x_{11}, came into the solution and represent, respectively, the amount by which the west approach volume exceeds its minimum volume and the amount by which the structural vector x_5 exceeds its minimum volume, as formulated in the constraints. The remaining slack vectors which did not come into the solution have little meaning in this model.

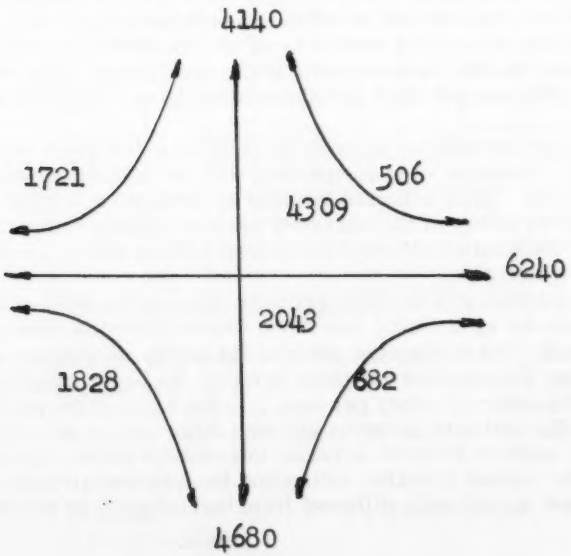
The sketch showing the solution as taken directly from the final tableau was not adequate for making a valid comparison with the Indiana State Highway Commission's solution. Their estimate included an estimate of service stops due to the limit access nature of the interstate system. Adding their estimate of service stops to the solution obtained in the final tableau above, the following solution was calculated.

Comparing this solution with the total estimate made by the Indiana State Highway Commission for each traffic movement (shown below), a close correlation was found. The differences between the traffic movements estimated by the Highway Commission and those found by the linear programming approach were on the order of twenty per cent. On the basis of the expected accuracy in any traffic estimate, a twenty per cent difference is not significant. Therefore, it appears from the Seymour interchange model, linear programming may be applied to traffic estimation for interchange design, yielding a solution not significantly different from that obtained by existing procedures.



It should be remembered that the traffic volumes as they are shown in the final tableau are not applicable directly to design. As is the case in many existing procedures of traffic estimation, it is necessary to apply a directional factor to each movement to determine the one-directional flow. It is also necessary to apply a projection factor to obtain a design for traffic volume for some year in the future. Although it was not done in this model, various growth factors could be incorporated in the original calculations which would enable projected traffic figures to be obtained directly from the final tableau.

In conclusion, a linear programming approach to traffic estimation problems seems to have three potential advantages over existing procedures.



1) The traffic movements in the final solution will automatically balance with the flow into the interchange. Some of the existing procedures for estimating traffic flow on an interchange do not yield a balanced situation; therefore, this would be an improvement.
2) Judgment comes into the linear programming solution in the estimate of minimum values and calculation of functional coefficients. Accordingly, it seems likely judgment can be applied with a greater degree of confidence under the linear programming approach than under procedures for estimating final traffic movements directly.
3) A third advantage comes about because of the ease of programming a problem set up in matrix form on a computer. Thus, where the traffic problems to be solved are numerous, the linear programming approach seems to hold even a greater potential.

Lastly, considering the potential of these, linear programming techniques to solve traffic problems systematically, yet accurately, it seems evident this approach to traffic analysis merits further study.

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Note: Paper 1918 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, HW 1, January, 1959.

*There will be no closure.

ADAPTABILITY OF INTERCHANGE TYPES ON INTERSTATE SYSTEM[a]

Closure by Jack E. Leisch

JACK E. LEISCH,[1] A. M. ASCE.—Mr. Love has brought out several important advantages of diamond-type interchanges at minor (rural) roads. He has also emphasized that local drivers would be familiar with the intersections along any minor road which connected with so important a facility as an Interstate highway; and, that motorists who use an interchange frequently are not likely to make wrong-way movements.

There will still be occasional, confused drivers, however, even on a local road, though less commonly than on a primary highway. Confusion may be caused by fatigue, liquor, fog or snow, as well as by lack of familiarity with the locale, so we cannot ignore the problem.

Furthermore, how "local" will these local roads be when the system is in full operation? The local rural road under discussion is typically located in a sparsely settled area. In mid-western or western states it is typified by the lightly-traveled section-line roads. Such roads are used for interchange locations, normally, only because there are no primary highways in the vicinity.

By way of illustration, if primary highway crossings occur at intervals of five miles or so in a rural area, the local road crossings in between are not provided with interchanges. On the other hand, where primary highway crossings are 10, 20, or even 50 miles apart, some of the intermediate local roads should be provided with interchanges.

The reason for interchanges at local roads, in some instances, is to provide a more flexible and useful system. That is, a certain spacing of ingress and egress facilities is desirable and essential to the maintenance and operation of the highway. Reasonably close spacing of interchanges also adds to the convenience of traffic potential to an Interstate highway. Facilities to provide such services as gasoline, car repairs, food, motels, and first aid will be located on the crossroads at or near the interchanges. (Service areas along Interstate highways, of the type found on turnpikes, are not permitted.)

Substantial volumes of traffic may result from service facilities at some of the interchanges with local roads. The problems thus created may be significant since such generation of traffic is not usually being taken into account in design of interchanges at local roads. To comprehend what this traffic may amount to, one need only to observe the activity at service areas along today's turnpikes. A comparable situation may be created at many of these crossroads. In some cases, it may be worse, since traffic making left turns and

a. Proc. Paper 1525, January, 1958, by Jack E. Leisch.

1. Chf. Highway Engr., De Leuw, Cather & Co., Chicago, Ill.

weaving maneuvers to and from service areas will become intermixed with both crossroad and interchange traffic.

Thus, traffic using interchanges at local rural roads will involve the unfamiliar driver. In some instances, the interchange will involve turning movements far in excess of through traffic on these roads. Accordingly, the simple diamond interchange will be subject to wrong-way movements as previously discussed in conjunction with Fig. 2. If the local rural road is to be limited to a two-lane highway, the parclo-B type interchange would be preferred since it greatly minimizes operational hazards by reducing the possibility of wrong-way movements.

In view of the above, the question is raised as to whether any crossroad justifying an interchange on the Interstate system can be operated as a two-lane road through the interchange. In designing for at least a 20-year period, it appears that most local crossroads should be designed through the interchange with protected left turns, or even as a fully divided facility. In such case, the diamond becomes a logical form of interchange. Fig. 20 illustrates a minimum design with longitudinal channelization.

Note that by introducing the divisional island, the possibility of wrong-way maneuvers is virtually eliminated. The additional pavement width precludes blocking of through movements on the crossroad by left-turning vehicles. Also, it minimizes the hazard of rear-end collisions involving standing vehicles waiting to turn left. Thus, the diamond with the divisional island may be considered a very desirable interchange at minor rural crossroads, with all the inherent advantages cited by Mr. Love.

Moreover, the use of the diamond is a step toward the obtainment of "uniformity of operational pattern" discussed previously in conjunction with Fig. 19. That is, greater use of the diamond, rather than parclo-B type interchanges (sketches B and C in Fig. 19), affords a more uniform pattern of exits on the Interstate system of highways.

In closing, it is again urged that all the States adopt that feature for the Interstate system of highways which will effect uniformity in the operational pattern.

INTERSTATE HIGHWAYS
ADAPTABILITY OF DIAMOND INTERCHANGE TO MINOR CROSSROADS – RURAL
WITH DIVISIONAL ISLAND
FIGURE 20

QUALITY CONTROL FOR LARGE HIGHWAY PROJECTS[a]

Discussion by John G. Dempsey

JOHN G. DEMPSEY,[1] M. ASCE.—The engineer and the construction industry have both been given a valuable definition of standards of engineering thinking and supervision, appropriate to quality-control during design and erection of engineering structures. This writer can testify to the truly outstanding uniformity and quality that can be attained when systematic quality-control methods are used on projects where trained engineering and supervisory staff are "enthusiastic about and believe in the desirable results that can be attained through this activity."

While the suggested standards for personnel to be assigned specifications, design and inspection seem somewhat idealistic, they are not for this reason less useful as qualifications to be aimed at, and the ideal of working for a high degree of uniformity within limits as set by reasonable specifications is well served by this paper.

Certain specific "self-functioning" features deserve comment. In urging as many lump-sum items as possible, there is no reference to the danger of running bidding up as the contractor tries to protect himself against unforseen increases in the cost of his work. Concerning finish screening (d) over batching bins, the writer adds his endorsement as both operator and engineer, just so the group being served are willing to pay the extra cost.

Regarding limitations of concrete temperatures in hot weather (f), except on very fully equipped jobs, this can be a serious problem, particularly when hot cement is also injected into the problem. Experience in the Lake Maracaibo area where both material and ambient temperatures run from 85 to 95° F. and mixing water runs 100 to 140° F., experience has showed that the judicious use of water-reducing retarders is a better answer than temperature limitations.

As to automatic batch plants (j), to most operators these have the distant appeal of expensive luxury. Outside of special work such as the large highway programs under discussion, or plants handling large quantities, it is believed the unit cost of fresh concrete, already high, would get out of bounds.

The paper urges the inclusion by reference in specifications of ready standards, such as AASHO, ASTM and ACI. This writer would further urge that when this is done, copies of these be furnished along with the plans and specifications. Many organizations will not have available the group referred to.

Concerning specifications once more, it is this discusser's belief that omission of the phrase "as determined by the Engineer" can often be very

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a. Proc. Paper 1626, May, 1958, by E. A. Abdun-Nur.

1. Gen. Mgr., Cadeco, Shell Oil Co., Estado Zulia, Venezuela.

expensive. In one instance where this phrase was omitted, sprinkling the sub-grade was called for before laying pavement. A thundershower did an ideal job on one section and the engineer ruled this a satisfactory substitute. On the basis of this ruling, the work was thrown out as not in accordance with specifications and the contractor could not be paid for his work.

In conclusion, while still other items might be matters for discussion on their individual merits, this paper, in urging the coordination of design, specifications and inspection through quality-control has re-defined the engineer's approach to construction in a most useful way. Smaller operations than the type of highway construction used as an example can very well afford to apply similar approaches and also reap benefits in speeded construction, lowered costs and improved quality of work.

REINFORCEMENT IN CONTINUOUS CONCRETE PAVEMENTS[a]

Discussion by William Zuk

WILLIAM ZUK.[1]—Although the writer is aware of the need and difficulty of developing analytical design equations for the proper amount of reinforcing steel in continuously reinforced concrete pavements, it is believed the Yerlici's equations contain some serious shortcomings.

In Yerlici's Eq. (3), he neglects the bond distance "a" which is unknown. This omission could be quite serious for small crack spacings. In fact in the author's numerical example on his page 7, his computed crack spacing "L" is only 35 inches. From theory(1) and tests(2) of the writer, most of this length would actually be in bond, so that the omitted unknown term "a" would be more important than the "L" term retained. The writer's ref. (1) presents an analysis of the same subject which does include a consideration of the bond effect.

It is also to be noted that Yerlici's Eq. (8) and (9) which he derived, are essentially the same equations which Vetter(3) presented in 1933.

The author's Eqs. (10) and (11) are perhaps of questionable value to a designer as the so called "average bond stress μ" is a rather unprecise term because the bond stress varies considerably throughout the length of "L". Yerlici is mistaken in his statement that this value of average bond stress "can be obtained from pullout bond tests". Since the steel in continuously reinforced pavement is subjected to bond stresses only in the region of the cracks, it is these peak bond stresses that are important, and not an average stress based on a bar length, much of the bar perhaps having no bond stress on it whatsoever. Therefore to obtain such a value of "μ" as needed in Eq. (10) and (11) elaborate instrumentation of such types as described in the writer's reference (2) is required.

In summary, although Yerlici's paper is very straightforward and simple, as is desirable for design use, the writer does not believe any fundamental information has been brought forward; and in the author's efforts to provide simple design equations he has made some questionable assumptions.

Needless to say, much more fundamental study is necessary to resolve the present uncertainties about continuous pavements and it is to the credit of the author as well as to the profession that Yerlici has devoted his time to this area of needed study.

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a. Proc. Paper 1799, October, 1958, by Vedot A. Yerlici.

1. Associate Professor of Civil Engineering, University of Virginia and Highway Research Engineer, Virginia Council of Highway Investigation and Research, Charlottesville, Virginia.

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2. Zuk, W., Bond and Transflexural Anchorage Behavior of Welded Wire Fabric, to be presented at the Highway Research Board, January, 1959.

3. Vetter, C. P., Stresses in Reinforced Concrete Due to Volume Changes, Trans. ASCE, Vol. 98, pp. 1039-1053, 1933.

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CONSTRUCTION AND USE OF MODELS IN HIGHWAY PLANNING

F. B. Crandall,[1] A. M. ASCE

This paper covers the construction procedure and materials used in building scale models of projected highway interchange facilities and the use made of completed models in highway programming and planning.

The use of scale models of projected highway facilities had its inception in the Highway Department as far back as 1944. Since that time there has been a progressively increasing volume of work in this particular area. Although the routine and mechanics of constructing these models is not a thing of great complexity, frequent requests are received in the Department as regards the manner of construction, material used, etc.

Model construction is restricted to major facilities of the freeway type, which usually incorporate traffic interchanges and structural features having a high degree of complexity and wherein, even for the engineer, it may be difficult to visualize from a flat plan and profile a complete "picture" of the ultimate facility. Over and above such uses made of the models within the Department from the design standpoint, they have solicited a great deal of interest outside the Department, and frequent requests are received for use of the models by sundry agencies and civic groups.

Model Construction

In the initial work with the models, scale of 1" = 30' was used and the work confined to single unit interchange facilities. Through the years the work has expanded to include extended lineal sections of projected facilities and with such expansion the scale of 1" = 50' was adopted, such scale being common to both horizontal and vertical dimensions—no distortion.

For the baseboard of the models, 1/2" waterproof plywood is used and the boards restricted to a maximum size of 3' x 4', with the over-all model being made of a series of these unit boards. Plywood carrying cases are made for the units, and the 3' x 4' size is about the maximum for ease of handling and transport. In laying out and positioning the model with respect to a series of boards, effort is made to have unit structures or interchanges fall on a

Note: Discussion open until June 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1924 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 1, January, 1959.

1. Traffic Engr., Oregon State Highway Dept., Salem, Ore.

single board. In the event of major change in design of a structure or traffic interchange facility, the alternate design can be made up on a standard board and substituted in the over-all model layout. Quite often alternate design requires revamping of the model (much to the chagrin of the man who does the work on the models). However, one of the prime purposes of making the model in the first instance is to study and detect any deficiencies in the design and attempt to improve thereon.

A flat plan, detail drawing of the facility on the scale of 1" = 50' is fastened to the series of boards, positioning the plan so as to preclude, insofar as possible, the overlapping of any structures on two boards.

The vertical datum is fixed by establishing the surface of the board as the lowest elevation to be encountered in the development of the model. Profile grades of the facility are established at 2" intervals using 1/8" wood dowels dapped into the baseboards or in some instances, balsa wood blocks used in lieu of the dowels. This same means is used to establish elevations of contour lines and other natural terrain control points. Finish nails driven into the baseboard can also serve for elevation cut-offs with respect to the natural terrain. Contour maps, field cross-section notes and photographs are used in developing elevations of existing roads, streets and terrain. Fig. 1 shows the model at this stage of construction.

A separate plan drawing of the facility is used as a pattern for cutting "roadway pavement" strips of 1/32" thick balsa wood. Major bridge structures, trusses, etc., are made up separately and positioned on the board as a unit. Fig. 2 shows this stage of development.

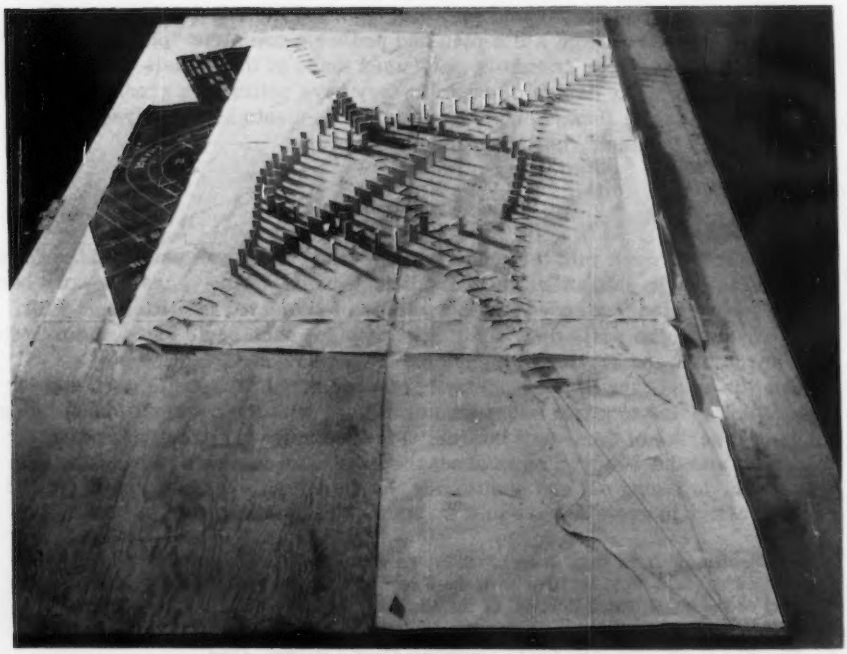

Fig. 1—Showing Plan with Start of Elevations

With the roadway fixed and the general skeleton of the model established, the natural terrain is brought up to the elevation with a filler of crumpled paper and rock wool insulation to within approximately 1/2" of final elevation. Two courses of wood putty (Schalks Wood Putty) are used to bring the ground surface to final elevation, the first being a scratch course to approximately 1/4" of final grade, and the finished course bringing the terrain to final elevation. This filling procedure makes for light weight of the model, and the two-course treatment with wood mastic allows more time for final molding thereof before setting up. Fig. 3 indicates this stage.

The curbs, channelizing islands, handrails and such details are made of balsa wood and are glued to the base model. The ingenuity of the model maker develops unique ways of simulating some elements of the model. For example, guard rail can be made from a strip cut from a "row of holes" in an IBM punch card. An alternative method is the same idea using fine wire mesh.

A coat of shellac is applied over the entire model surface as a seal coat for a subsequent application of paint. The model is then painted in appropriate colors to indicate pavement texture, water, grass, etc. Various degrees of embellishment can be made as to trees or other natural growth which can be simulated with pieces of sponge dyed to color. For purposes of general orientation, scale replicas of houses, buildings and such existent landmarks can be added to the model. As a general rule, it is necessary only to include those buildings, houses, etc., in the immediate vicinity of the projected highway facility. Information and dimensional data for construction of houses,

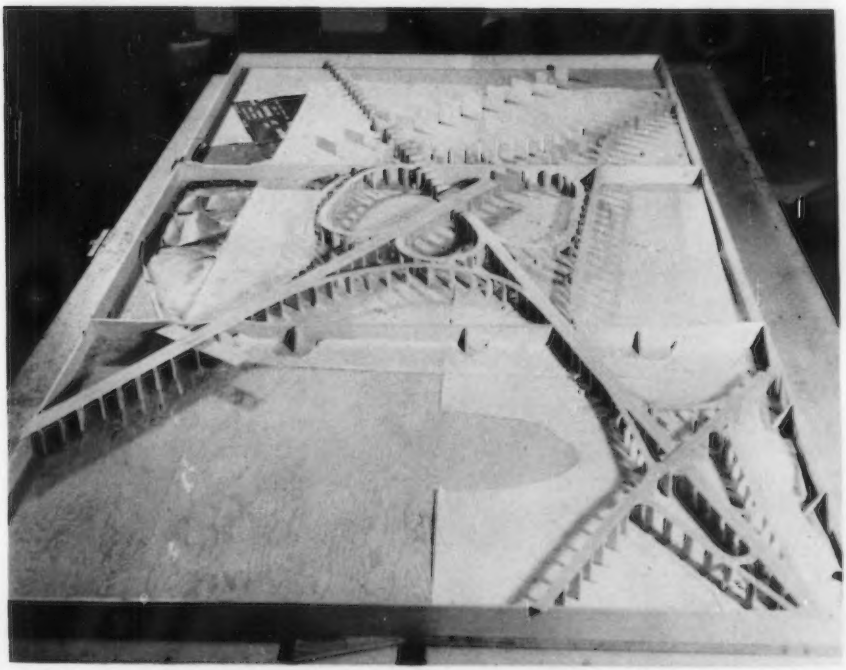

Fig. 2—Elevations with some road surface in place.

buildings, etc., are obtained from Sanborn maps supplemented by photographs. Roads, streets, and permanent physical features are identified by labels pasted on the model, and with the title and north arrow the model is complete. Fig. 4 shows a completed model.

Lightweight plywood carrying cases are made for the individual board sections of the model for use in transportation and storage. Several lag screws through the bottom of the carrying case into the baseboard of the model precludes shifting and possible damage in transport. A unit board plus carrying case will weigh approximately 80 pounds.

Use of Models

For projected highway facilities of relatively simple design, the "picture" can be fairly well visualized from a study of a flat plan and profile drawing, however, when a projected facility becomes more complicated, involving numerous structures, multiple ramps, etc., it is difficult sometimes even for the engineer to fully visualize the ultimate facility from detailed drawings—certainly the layman is lost in any attempt to visualize the end result from a study of flat plan and profile. From the standpoint of the construction engineer the model gives a clear concept and preview of the prototype and an opportunity to correct any undesirable construction features. The model furnishes a useful picture in the planning of stage construction and likely detour routes for traffic while the facility is under construction. The

Fig. 3—Completed road surface and terrain.

landscape engineer has found the model useful in developing planting arrangement where landscaping is to be made a part of the completed project.

To the traffic engineer, whose concern is the operating features of the completed facility, the models serve to point up features of design which might not be apparent from a study of drawings and with particular reference to undesirable sight-distances which may result from a combination of vertical and horizontal alignment with possibly a bridge abutment coming into the picture. The models are of considerable aid in determining the need and placement of traffic control signs, and although the matter of signing may seem relatively unimportant there have been instances where proper signing was practically a physical impossibility by reason of design features. The models also have helped in laying out proper lane markings, particularly in the instance of multiple lane facilities.

The right of way acquisition incident to a new freeway facility is a sizable operation in itself, particularly in built-up urban areas involving high property values where in some cases the right of way may be the bigger item money-wise, rather than the construction cost. The very concept of freeway design disallows direct access to abutting properties or any intersections at grade. The servicing of abutting property traffic-wise is an important factor in right of way transactions. The provisions for servicing abutting properties usually involves development of a secondary road or street net, utilizing existing streets and roads, or in some cases, the addition of flanking frontage or collector roads. These elements incorporated into the model provide the right of way agent as well as the property owner, a clear indication as to what

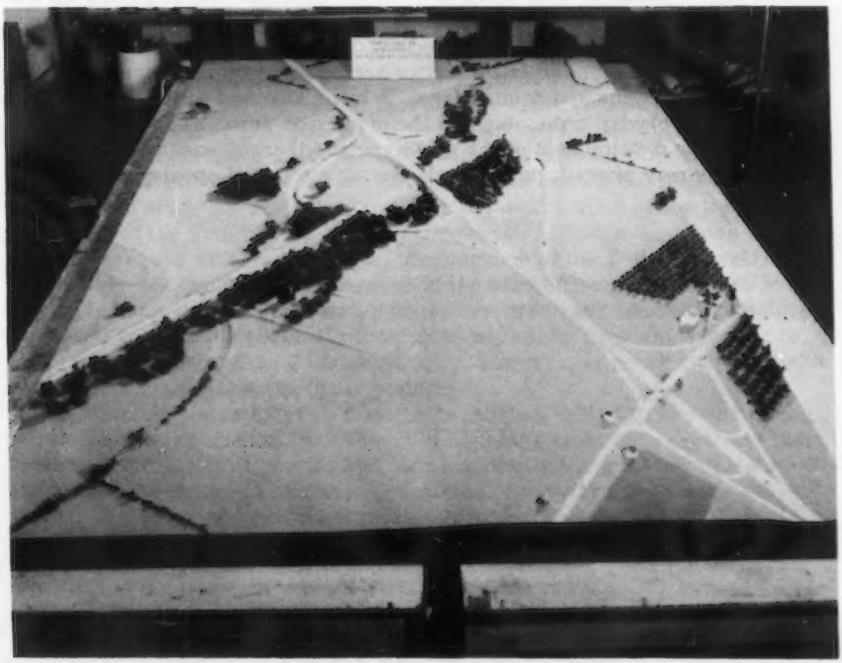

Fig. 4—Finished model.

the situation will be with the new facility in operation. Again, some adjustments or modifications may be made that will provide better servicing of abutting properties and possibly make for some difference in the final cost of land acquisition.

Probably the greatest use to which the models are put is in the area of public relations. The passage of necessary enabling legislation in 1947 that would permit the development of the freeway type facility was not an easy accomplishment. Even after passage of enabling legislation there were numerous skeptics who had to be "sold" on the freeway concept as being a necessary adjunct to our growing transport system. Probably the greatest single factor in selling the idea to this negative group has been the actual construction and putting into operation of segments of the freeway facilities. The actuality has shown that the old traffic patterns can be adjusted to the new freeway system providing safer and more expeditious movement of large volumes of traffic without any deterioration of land values—much to the contrary, studies show that there is an actual increase in land values by reason of freeway development. Along the way the models of projected facilities have played a part in the period of evolution in obtaining acceptance of the individual and collective public. Every opportunity is taken to place the models on display at civic gatherings as well as official meetings, conferences, etc.

Frequent quips and cartoons play on the intricacies of some of the interchange layouts that have come off the design boards and put into operation. Particularly in urban areas, the multiplicity of desired movements on the part of various traffic streams results in somewhat complicated layouts. It is true that negotiating interchanges on these freeways and in getting on the proper ramp, etc., that one must plan his trip a bit farther ahead than his radiator cap in order to get to his desired destination. The more intricate interchange layouts tend to fall in urban areas where there is greater multiplicity of trip origins and destinations. A large segment of the traffic, however, is the everyday commuter and the models do serve to orient people in advance of the development of the prototype and thereby eases the degree of confusion as may prevail, particularly during the initial opening of the facility.

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THE HIGHWAY COST ALLOCATION STUDY[a]

G. P. St. Clair[1]

ABSTRACT

Objective is to determine costs occasioned by, and benefits derived from use of Federal-aid highways by vehicles of different dimensions and weights. Benefits to non-users are also studied. Data are supplied by highway departments and universities; analysis by Bureau of Public Roads. Final report is due January 1961.

By shifting the support of Federal highway aid from a general-fund base to a user-tax base, Congress, in the Highway Revenue Act of 1956, materialized on the Federal stage the pale ghost that has for many years haunted State highway departments and legislatures—the highway cost allocation problem. Congressional awareness of the issues involved in this action was made evident by the provisions of Section 210 of the Act, directing the Secretary of Commerce to study the subject of equity in the distribution of the tax burden for support of the Federal-aid highway program. Although the States are still greatly concerned with this problem, the entrance of the Federal Government into the user-tax field and the increase in the size of the program tend to invalidate in some degree the findings of studies previously made in individual States, and suggest the necessity for a re-study of the problem from top to bottom. The Highway Cost Allocation Study, however, is concerned only with Federal taxation for the support of highways.

The central issue of highway taxation is the dual one of first determining the relative contribution to the support of highways from motor-vehicle and non-motor-vehicle tax sources, and, second, determining the equitable allocation of motor-vehicle taxes among vehicles of varying dimensions and weights. This two-pronged problem is confronted at State and local levels

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a. Presented at the June 1958 ASCE Convention in Portland, Oregon.

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each time a State legislature passes a highway-tax law or a county or city council changes the road-tax levy. On the national scene, it has been dealt with twice before—first by the Federal Coordinator in the study culminating in his 1940 report "Public Aids to Transportation,"(1) and second by the Board of Investigation and Research in a series of reports published in 1945, the most pertinent of which was that entitled "Public Aids to Domestic Transportation."(2) There were numerous State studies of this subject before World War II and there have been a large number in the years since the war. Parties at interest to the controversy, conspicuously railroads and trucking groups, have also contributed analyses of the problem.

The provisions of Section 210 of the 1956 Act do not give the Secretary blanket authority to study the subject of highway tax equity. Instead, they instruct him to proceed in a rather definitely specified manner. The study must determine the effect on design, construction, and maintenance of Federal-aid highways of the use and frequency of use of vehicles of different dimensions and weights. In determining the proportionate shares of highway-user tax responsibility, it must take these effects into account; but it must also take account of the benefits derived by the different classes of users from their use of the Federal-aid highways. Finally, the Secretary is directed to study "any direct and indirect benefits accruing to any class . . . in addition to benefits from actual use of such highways" which can be attributed to public expenditures on the Federal-aid systems.

These rather clear-cut specifications provide a framework upon which the structure of the study must be erected. Fortunately, the language used follows the lead of the most fruitful work that has been done in this field, and at the same time makes provision for alternative approaches and some breadth of treatment. In the past, the two principal avenues of approach to the motor-vehicle tax problem have been that of costs occasioned, and that of benefits derived, by the use of vehicles of different sizes. Section 210 requires that both of these avenues be traveled and suggests that an acceptable solution may be found at their intersection.

User vs. Non-User Tax Support

Attempts to divide the field of highway taxation equitably between motor-vehicle and non-motor-vehicle tax sources have seldom produced solutions that were wholly satisfying even to the investigators. Public acceptance of user taxes, particularly gasoline taxes and registration fees graduated with size or weight, has gradually diminished the importance of the earlier sources of highway tax support—ad valorem property tax levies, special benefit assessments, and general revenues—although they still contribute a substantial part of the support of county and local roads and streets. Estimated highway revenues from these sources in 1957 were $1.4 billion, of which about $700 million were revenues of cities, $580 million were those of counties and other local rural units, and $90 million were State funds. This total is to be compared with about $4.2 billion in highway revenues from State and local road-user tax receipts in 1957, and about $1.4 billion in Federal funds.

It is sometimes argued that, since practically all highway use is motor-vehicle use, there remains no real reason for other than user taxes for the support of highways. The modern toll turnpike, of course, affords an example of the highway fully supported (with a few exceptions) by user contributions,

although they are not called taxes. In a few States, all rural roads are now supported fully out of user taxes, but there remains a vigorous body of opinion in favor of deriving a substantial part of the support of highways from property taxes or general revenues, or both.

From its inception, the Federal-aid highway program was supported by the general fund of the Treasury. During most of these years, there has been a body of Federal excise taxes on motor vehicles, motor fuels, tires, and other automotive products, gradually increasing in their rates and in their yield to the Federal Government. During the years immediately preceding 1956, there grew up the phenomenon called linkage, by which the Federal-aid authorizations for highways were associated in the minds of many people with the even greater receipts from the Federal excise taxes, which came to be regarded as user taxes in fact although not in law. In the Highway Revenue Act of 1956, the Rubicon was crossed, and the Federal-aid program went over fully to a user-tax basis, through the direction of part of the existing Federal excise taxes into the Highway Trust Fund, plus the enactment of additional imposts, including an increase in the motor-fuel taxes, the truck and bus excise tax and the tire tax; and a special tax on trucks having gross weights of more than 26,000 pounds.

Section 210 directs the Secretary of Commerce to investigate the matter of non-user benefits, those benefits "in addition to benefits from actual use of such highways." The inference is that Congress wishes to take a second look at its own action in shifting squarely to a user-tax base. The plan is to provide the Congress with such information, not only by making a comparison of vehicular and non-vehicular benefits, but also by following the lead of previous investigators in the field who have blazed other trails in the effort to find a key to the proper division of user and non-user tax support. As Zettel[3] and others have pointed out, there is danger in relying solely on a comparison of vehicular and non-vehicular benefits, since the indirect benefits are so largely the result of reduced transportation costs—which is to say vehicular benefits—and so may cause double counting in the assessment of tax responsibility.

Allocation Among Different Vehicle Classes

Students of highway taxation have had somewhat greater success in devising approaches to the problem of distributing motor-vehicle tax responsibility among vehicles of varying dimensions and weights. Since no single theory has met with universal acclaim, it was decided to use more than one, and produce alternative solutions, the findings of which may be compared.

A method found attractive by numerous investigators is the gross-ton-mile solution, which postulates that highway-cost responsibility and the consequent road-user taxes should be allocated in proportion to the gross ton-miles of travel by each size and weight group of vehicles from the passenger car to the heaviest combination. Although advocates of the method point out that weight and distance are prime factors in any calculation of motor-vehicle tax responsibility, the gross ton-mile is advanced not as a measure of costs occasioned or benefits realized, but as a unit of highway use. Ton-miles are to be sold over the counter like yard goods, with no discounts for purchases in quantity.

Opponents lay stress on a certain diversity in the significance of the unit. They point out that the ton-mile, unlike the foot-pound, is not a uniform

measure of energy, for it takes more energy to move ten 2-ton automobiles a mile than it does to move one 20-ton trucking rig the same distance. They insist that, although the ton-mile is a useful unit in certain contexts and within certain ranges, it cannot be applied uniformly to passenger and freight transportation, to movement on different kinds of highways, or even to widely different kinds of freight transportation, such as the pick-up truck and the heavy combination. This great disparity of viewpoint, often reflecting differences in commercial interest, coupled with the popularity of the gross ton-mile procedure among highway tax investigators, makes imperative a thorough study of the method in the Highway Cost Allocation Study, and its use as one of the alternatives in allocating highway cost responsibility among vehicles of different types and sizes.

Even so, the Secretary is directed by Congress to base his findings in large part on the highway costs occasioned by the use and frequency of use of vehicles of different sizes. This approach is often called a differential-cost method of allocating highway cost responsibility. The incremental solution, given great prominence in the work of the Federal Coordinator, is based on the concept that there are certain joint or common highway costs which should be shared on a uniform basis by all vehicles, and that subsequent increments of cost are to be shared by successively smaller groups of vehicles in increasing order of size. This method has been adopted for use in the Highway Cost Allocation Study; and the job of achieving the incremental solution is perhaps the principal effort of the project. Attention will also be given to the cost-function method, which purports to divide highway costs into three classes: First, those unaffected by either weight or distance traveled, and thus subject to allocation on a per-vehicle basis; second those affected by extent of travel but not by vehicle weight, and thus subject to allocation on a vehicle-mile basis; and third, those costs affected by size or weight of vehicle, and thus subject to allocation on a size or weight basis.

Section 210 also directs the Secretary to take into account the benefits derived by different classes of users, which is to say by vehicles of different dimensions and weights. The progress made in recent years in the benefit-cost analysis of highway projects has provided a lead for this part of the analysis, and there is in progress a so-called differential benefit solution, in which the attempt is being made to allocate cost responsibility in proportion to the benefits to be derived from the Federal-aid improvement program by vehicles of different sizes. The benefits referred to are (1) reductions in direct operating costs, such as fuel consumption, (2) savings in time of travel, and (3) savings in accident costs. A fourth factor, that of reduction in the strains and discomforts of congested driving, is difficult of evaluation but is being given consideration in the analysis.

The early work of Agg, Winfrey, and Moyer at Iowa State and that of McCullough, Baldock, and their aides in the Oregon State Highway Department laid the groundwork for developments in this field. More recent work by Saal, May, Carmichael, Greenshields, and others has developed much new information about vehicle performance under varying conditions, and particularly about the interacting effects of rise and fall in the road, and weight-power ratio in the vehicle, on travel time and motor-fuel consumption rates. Currently work is being done to measure the effects of traffic density and highway profile on the operating characteristics of motor trucks of different sizes under both rural and urban conditions.(4)

Planning and Organization

The job of developing the data for the several analyses described in preceding paragraphs is a formidable one; and the Bureau of Public Roads is greatly indebted to the State Highway Departments of all States for performing the major part of this data-collecting function. In Washington the Highway Cost Allocation Study is directed by a small central organization, the chief function of which is planning and liaison, except for the fact that this central group is charged with the responsibility for the incremental solution in its final stages of analysis, as well as for various special jobs not readily delegated elsewhere. Primarily, the project is operated through four planning committees, with membership from the Office of Engineering as well as from the various divisions of the Office of Research. One of these planning committees deals with vehicles and traffic, another with highway needs, a third with incremental design standards and cost factors, and a fourth with highway benefits.

The data-collecting phases of the study have been found to consist of certain major blocks of work. The first to be undertaken was that of obtaining an adequate classification of commercial vehicle registrations—buses, trucks, and combinations—by type, class of use, visual classes, and gross weight groups, together with information on annual mileages and miles per gallon. This project was undertaken by the Highway Statistics Branch and became a job for the planning people in the State highway departments. By cooperative agreement with the Bureau of Public Roads, the National Association of Motor Bus Operators and the American Transit Association took on the job of supplying some special information on the numbers and operating characteristics of buses.

The second big task was that of making an estimate of the needs of all the Federal aid systems. In the case of the Interstate system this was simply an extension and further breakdown of the study undertaken for apportionment purposes under Section 108d of the 1956 Act. Under Section 210 the objective was to determine the total costs for which responsibility must be allocated. This part of the job was carried to the point of making needs estimates for all road and street systems, in the belief that Congress could use the additional background data. Again, this was a job for the State highway departments and is being handled in the Bureau of Public Roads by the Highway Investments Branch.

In order that the various studies should be based on accurate estimates of volume and type and weight composition of traffic in all States, the annual traffic counting and weighing program was greatly expanded for the year 1957, and it is felt that reasonably accurate estimates of the composition of travel on all Federal-aid systems will be forthcoming. Supervision of this job at the Bureau of Public Roads was undertaken by the Planning Research Branch. The State highway departments also furnished forecasts of motor-vehicle registrations, traffic volume by systems, and highway-user revenues for use in the analytical work of the study. The Bureau's Highway Economics Branch undertook the job of analyzing the State forecasts.

Perhaps the most demanding, if not the most burdensome, task thrust upon the State highway departments was that of supplying design standards and cost factors for the incremental solution. In this solution each pertinent element of highway cost—in particular, grading, pavement, base and subbase, structures and maintenance—must be analyzed to determine the effects of

vehicle size and weight on designs and practices, and corresponding costs. By means of a manual sent through the field offices of the Bureau the engineers of the State highway departments were asked to describe their structural and geometric design standards for road construction, for a series of traffic-volume ranges, on each Federal-aid system; and to give corresponding costs per mile. Conditions of high, normal, and low percentages of heavy vehicles were to be considered. They were then asked to indicate the extent to which these designs would be altered and costs reduced, first, if traffic on the Federal-aid systems included no vehicles heavier than 2-axle, 4-tire trucks, and second, if the traffic consisted entirely of passenger cars and similar light vehicles. Questionnaires similar in import covering the subjects of structures and maintenance followed the road construction inquiry.

The response to this survey of expert engineering opinion has been heartwarming. The engineers in the States proved themselves willing to take definite positions on the questions at issue, in the face of the prospect that the AASHO tests in Illinois may produce contrary evidence. The State responses are now being reviewed by a panel of engineers in the Bureau. From this review, with interpolations for intermediate conditions of loading, will come a set of incremental design standards and cost factors, by Census regions, to be used in the incremental solution.

The study of highway benefits produced two additional blocks of work. The university studies of variation in truck operating costs being carried on under the general direction of the Traffic Operations Division at the Bureau were cited earlier. In addition to the work now in progress at the University of Washington, projects were conducted at Ohio State University and the University of Michigan; and one was conducted independently by Professor Taff of the University of Maryland. The differential-benefit analysis has also produced a formidable task for the State highway departments, in that a selected group of States has been asked to re-analyze portions of the needs-study data in order to estimate the magnitudes of those physical changes, of which reduction in rise and fall is a prime example, that are productive of savings in operating, time, or accident costs.

In order to gather data about the indirect benefits, or, more broadly, the economic and social consequences of highway improvements, it was necessary to organize a group of university and other research studies, well scattered throughout the country. Some of these are conceptual studies, designed to build a groundwork of theory on the incidence and flow of effects, both favorable and adverse, that result from the construction of highway facilities. The greater number are data-gathering studies that will disclose information about actual realized effects, particularly changes in land values, land uses, and business volumes ensuing from the construction of expressways, bypasses, main highways, and secondary roads. Some of these studies were arranged directly with the cooperators by the Bureau of Public Roads; but most of them were Federal 1-1/2 per cent fund projects in which the State highway departments and the universities were the contracting parties. In Washington these projects were put under the direction of the Division of Highway and Land Administration.(5)

The Looked-For Product

The success of the Section 210 Study, if it is to be a success, will be largely due to the able and productive efforts of the engineers in the State highway

departments, not only those in the planning departments, but also design engineers, bridge engineers, maintenance engineers, and others who have contributed and are contributing to the enormous volume of data the highway departments are supplying. A great deal of credit is also due to the professors and research associates in numerous universities and other research agencies who have undertaken projects in the field of economic impact and the determination of vehicular and non-vehicular benefits.

The final report on this project was required to be submitted not later than March 1, 1959. Because the results of the AASHO Road Test in Illinois will not be available for use in a report with such a due date, the Secretary of Commerce in the Second Progress Report on the Highway Cost Allocation Study asked for an extension to January 3, 1961. Under the terms of Public Law 823, 85th Congress (72 Stat. 983) this extension was granted, thus assuring that the final report of the Highway Cost Allocation Study will embody the findings of the Illinois tests with respect to the design requirements of vehicles of different sizes. It is not to be expected that even the 1961 report will be the last word on this subject. The factors affecting highway-cost responsibility are not static. They vary with progress in the design of highways and concomitant changes in vehicle design. What can be hoped for is that the results of this study will mark a significant advance in the attack on this difficult problem.

Those connected with the project are well aware that there are other than technical considerations in the field of highway taxation. Congress must weigh other matters in addition to the data and findings of the Highway Cost Allocation Study. Those whose interests may be affected favorably or adversely must have their say. Out of the legislative process it may reasonably be expected that there will come an acceptable compromise in the adjustment of the provisions for support of the Federal-aid program. Further technical work will always be needed to assist Congress in making future decisions. One can only hope that this particular job will be adequate for the years directly ahead.

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INVENTORY OF HIGHWAY NEEDS[a]

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ABSTRACT

The Federal-Aid Highway Act of 1956 required each state to prepare cost estimates of the needs of the various road systems within the state. This paper outlines the procedures employed in Oregon to develop the estimate of needs for each of the 12 systems considered to provide adequate highways, roads, and streets for 1975 traffic volumes.

The Federal-Aid Highway Act of 1956 in addition to appropriating federal money for highway construction, directed the Secretary of Commerce to conduct several basic studies desired by Congress for their evaluation of the highway transportation problems. Section 210 of the Act outlines an investigation of equity in federal taxation for support of the Federal-Aid Highway Program. The investigation called for under this section has been given the title of the "Cost Allocation Study". This study has been subdivided into several different phases one phase of which was the development of estimates of needs of various road systems, which is the subject of this paper. Section 108(d) of the Act required an estimate of cost for completing the Interstate Highway System. Although the Interstate Highway Study was included as a separate section of the Act, the estimates contained in the study were required for the Cost Allocation Study.

Principal emphasis in the development of the estimate of needs of various road systems was on the Federal-Aid Highway Systems. However, estimates of needs were obtained for non-Federal-Aid Systems so that the study of Federal taxation could be made with proper consideration given to the needs of all road systems.

The Manual of Procedures for the preparation of needs estimates was presented to the State on April 1, 1957 and instructions were reviewed quite

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a. Presented at the June 1958 ASCE Convention in Portland, Oregon.

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thoroughly at a conference attended by both State and Bureau of Public Roads personnel. The estimate of needs was required in the Washington D. C. Office of the Bureau of Public Roads not later than October 1, 1957. Some portions of the report, however, were required before that date.

An important feature in the development of the estimate of highway needs was the requirement that the estimates should not be affected by the ability of financing and executing the program. This was done to develop a true picture of highway needs rather than an estimate of needs based on the availability of financial means for satisfying needs requirements.

The intent of Congress that the Interstate System be completed over a 13-year period, with an allowance of additional expenditures for two more years, dictated the period during which roads and streets should be improved to adequate standards. The period used for the needs study was the 15-year period from July 1, 1956 to July 1, 1971. Although the period selected for the study was the same for all systems, there were certain differences as to the degree of adequacies that would be obtained on the Interstate System and other systems.

The estimate of needs was made for all the roads and streets within the state. To provide additional detail, the roads and streets were classified and data prepared for the following 12 systems:

1. Interstate, rural
2. Interstate, urban
3. Other FA Primary, rural
4. Other FA Primary, urban
5. FA Secondary rural, State jurisdiction
6. FA Secondary urban, State jurisdiction
7. FA Secondary rural, local jurisdiction
8. FA Secondary urban, local jurisdiction
9. Other State Highways, rural
10. Other State Highways, urban
11. Other rural roads
12. Other city streets

The urban mileage for the Federal-Aid Systems was mileage in urban areas established for cities and contiguous areas with a population of 5,000 or more as determined by agreement with the State and Bureau of Public Roads. The distribution between rural and urban for the non-Federal-Aid Systems was based on the State's practice of classifying urban mileage as mileage within any incorporated city. All mileage on other highways under federal jurisdiction such as Forest Highways, Indian Service Roads, et cetera, was included in the study under the appropriate system classification. In the event that the section of highway was classified as two or more systems, it was included in the study in the system with the highest classification.

For the Federal-Aid Systems, a high order of accuracy was attained with estimates obtained for each section of road. For other roads, sampling techniques were used to develop the desired information. The needs estimates covered not only the mileage existing on each system on July 1, 1956, but the additional mileage required because of changes in highway locations and system designations anticipated during the 15-year period of the study. The final estimate of needs represents the needs for each system as it should be in 1971.

One of the first steps required in the preparation of the estimate of needs was the study of the potential traffic volumes anticipated on each section of road by 1971, 1975, and 1981. To provide as much detailed information as possible and still keep the volume of work within the capability of the available manpower, traffic projections were made on an area basis. In the development of traffic projection factors, consideration was given to normal traffic growth, generated traffic, and development traffic. The state was divided into economic areas for the development of traffic projection factors. Within each of these eight economic areas separate factors were developed for each of the 12 systems. Unless special conditions were known to exist for a particular section of road, the area factors for the projection of traffic volumes were used in estimating future traffic volumes.

For the estimate of needs for the Interstate Highway System, the Bureau of Public Roads and the American Association of State Highway Officials arrived at the minimum standard desirable for improvement of the Interstate Highway System. These standards were used by the states as a guide in preparation of cost estimates for the development of the Interstate System, with the understanding that these were minimum standards, and that modifications would be allowed where necessary.

The development of needs for the Interstate Highway System which had been completed as a separate study (108 d) was used with certain modifications. The needs of the Interstate System were developed by identifying the deficiencies that would exist on each section if it were to remain in service until 1975. A determination was then made of what construction improvements and/or relocations were necessary to overcome these deficiencies in order to make each section of road comply with the Interstate Standards for 1975 traffic.

The time allowed for the preparation of these estimates of needs did not permit a complete field survey in the establishment of locations, so that accurate estimates could be prepared. It was, therefore, necessary to base the estimates upon reconnaissance surveys. All reconnaissance surveys were made by standard field methods and field observations were made for each section of highway. For some sections of the Interstate Highway it was necessary to use preliminary locations for the development of these estimates.

To accomplish the preparation of estimates in the time allowed, it was necessary to assign 20 to 25 locating crews to this project from December 1, 1956 to April, 1957, with central control handled from headquarters. The field personnel under the supervision of the Chief Locating Engineer ran field reconnaissance surveys on every portion of the Interstate System. Each locating crew assigned to the task had a definite section of the Interstate System for which it was responsible for the preparation of the estimates of quantities necessary for the construction of this section to Interstate Standards. Field estimates were then reviewed in detail by the Chief Locating Engineer in close cooperation with the Bureau of Public Roads. When it was determined that the estimates of quantities were reasonable for the section under study, unit costs were assigned by the Cost Analyst, and the estimates of costs for improving the survey section to the desired standards were completed.

The preparation of estimate of needs for the Interstate Highway System required approximately 70,400 man-hours. This includes the field work and all of the office analysis.

The preparation of cost estimates of highway needs for the Cost Allocation Study did not allow as detailed a survey as used for the Interstate Highway

System. For the Interstate Highway System the cost estimates previously prepared were utilized for both studies. For the Cost Allocation Study, it was necessary to re-arrange the Interstate Highway cost estimates to fit the forms required by this study.

For the other highway systems deficiencies were identified in accordance with anticipated traffic conditions for the year 1971. These deficiencies were based on a set of "tolerable conditions" rather than a design standard. If a deficiency was found based on tolerable conditions, the cost of correcting the deficiency was prepared based on providing an adequate road section for 1975 traffic. Right of way for all highways was estimated for all sections which would require construction by 1981 of additional lanes to meet capacity needs.

To accomplish the preparation of an estimate of needs and to maintain as much uniformity in the estimate as possible, one Locating Engineer was selected in each Division to prepare the estimate for his Division. These Locating Engineers were given detailed instructions and worked under the close supervision of the Chief Locating Engineer. For the Federal-Aid Primary System and Federal-Aid Secondary System on state highways it was necessary for the Locating Engineer to make a "windshield" reconnaissance survey of each mile of highway. For this purpose deficiency sheets were prepared to aid the locator in recording deficiencies as he traveled the highways. This information was then converted to the estimates of quantities to eliminate these deficiencies. Here again, quantities were computed by the locators, and unit costs assigned by the Cost Analyst. For the Federal-Aid Secondary System on county roads, the County and City Relations Section has been maintaining for a number of years a record of an estimate of cost necessary to bring each mile of this system up to the required standard. Each Locating Engineer made a sample study in his Division of the Federal-Aid Secondary System on county roads, and from this sample cost estimates were prepared. These cost estimates were then compared to the office records and served as a guide in modifying the office records so that they could be used for the study.

For the other rural roads, it was not possible to make a complete study of the entire mileages. It was, therefore, necessary for each Locating Engineer to study a sample of the mileage within divisions stratified by surface type and terrain. Approximately 15 per cent of the mileage in each Division was included in the sample. Cost estimates prepared for the sample were then expanded to represent the cost estimates for the total mileage for each Division. For city streets one man was assigned to the Portland Metropolitan Area—which for this study included all of Washington, Multnomah, and Clackamas Counties. A study was made of all city streets within this area. For needs in other cities a stratified sample by surface type and terrain was taken within each Division, and cost estimates prepared from these samples were expanded to represent cost estimates for the entire mileage.

Additional information was received from each of the federal agencies concerned with road construction in the state, and cost estimates and mileage of additional roads required were supplied to the Highway Department for inclusion in the report.

Exclusive of the man hours required for the preparation of the Interstate Highway System, approximately 12,000 man-hours were required to develop the estimate of needs for the various road systems as required by the Cost Allocation Study. This time does not include work which had been done previously by the Department for other purposes or other agencies.

An important feature of the estimate of needs and one that made the task somewhat difficult, was the extensive itemization of costs. Some of these itemizations were logical byproducts of the estimating processes, whereas others had to be developed separately. It was necessary to prepare cost estimates for each of the 12 systems by the surface type—low, intermediate, and high. High surface type was further subdivided to two lane, four lane, and six lanes and over. Within systems and surface types itemization of cost was required as follows:

Federal-Aid System

I. Through Traffic Road

A. Terrain (flat, rolling, mountainous)

1. Right of way
2. Grading, Drainage
3. Utility Adjustments
4. Surface and Base
5. Shoulders
6. Structures, over 20'
7. Roadside Development
8. Traffic and Pedestrian Service

B. Construction Operation

1. Resurfacing
2. Minor Widening
3. Major Widening
4. Reconstruction
5. Construction on New Location

II. Interchanges

1. Grading, Drainage
2. Surface and Base
3. Shoulders
4. Structures over 20'
5. Traffic and Pedestrian Service

III. Frontage Roads

Same as Interchanges

IV. Climbing Lanes

1. Grading, Drainage
2. Surface and Base

Non Federal-Aid

1. Right of Way
2. Grading
3. Surface
4. Structures

In addition to the estimate of cost for construction, information was also required on actual and estimated maintenance requirements for each of the 12 systems for the years 1956, 1971, and 1991. Maintenance cost information

for 1956 was required for each of the surface types; unsurfaced, low, intermediate, and high by the maintenance items of (1) roadside, (2) surface and base, (3) shoulders, (4) traffic services, (5) snow-ice-sand. Estimated annual maintenance costs by road maintenance items were required for typical conditions at an interchange, on a mile of frontage road, and on a mile of climbing lane.

The final item required to complete the estimate of needs was the percentage factor for estimating costs of administration for each of the 12 systems. This factor applied to the combined costs of construction and maintenance.

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

VEHICLE WEIGHT PHASE OF THE SECTION 210 STUDY

C. K. Glaze[1]

Truck weight and usage data are essential in highway design, administration, and finance. Section 210 weighing was an extension of weight surveys made since 1936.

Weights were obtained at locations representative of each of the rural and urban Federal Aid highway systems. The vehicle miles traveled by each vehicle type on each system were computed.

Truck weight and usage data is essential to highway engineers in designing a structurally adequate roadway. Not only is current data needed, but a knowledge of weight and usage trends is also required in order to permit estimates of the future loadings and repetitions to which the highway will be subjected.

However, at least equally important is the need for such information for the broader purpose of highway administration and finance. Without factual and detailed knowledge of truck and other vehicle weights and usage, it would be impossible to determine between the individual vehicle types the relative tax responsibility for road and highway purposes. Moreover, changing conditions of vehicle usage and application require periodic revaluation of this basic data to render it valid.

All theories of road user tax responsibility rely to a large extent upon weight and usage data. Collecting such data has traditionally been a function of the Highway Planning Divisions in the various states. Without this data no road user taxation and highway financing study could "get off the ground", so to speak. This data vividly shows the trends: rapid increases in total motor vehicle travel, coupled with the increasing application of the larger vehicle types, increased usage of the individual larger vehicles, and their increased and more efficient loading.

Section 210 of the 1956 Federal Aid Act requires a determination and report on the effects on highway design, construction, and maintenance occasioned by the use of vehicles of various sizes and weights and their frequency of occurrence in the vehicle stream, together with an evaluation of the proportionate share of the costs attributable to each class of vehicle as well

Note: Discussion open until June 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1928 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 1, January, 1959.

1. Princ. Planning Engr., State Highway Comm., Dept. of Highways, Olympia, Wash.

as the benefits derived from their use of the highways, and a determination of benefits being derived from other than use of the highway.

To carry out these requirements of the Act, current, factual, and detailed knowledge of vehicle usage and weights is necessary. Moreover any variations found to exist among the different highway systems would of necessity also be required. To collect this information, the vehicle weighing phase of the Section 210 Study was conducted.

Obviously, knowledge of actual usage practice and experience is the only answer since legally established limitations are arbitrary, of extreme variation in enforcement, and give no indication of variations amongst the various highway systems. Even within an individual state, variations in loading practices occur, simply as a result of the differences in the economies within the State, as well as differences in enforcement activities. When it is realized that such differences are greatly magnified between states, it is obvious that actual usage data under existing laws and enforcement with their own built in variations, can be the only basis for tax studies.

The Section 210 weighing operations were an extension of surveys being made in the State of Washington since 1936. The State drew upon its experience in conducting these surveys in designing the vehicle weighing program utilized for the Section 210 Study. A total of over 13,000 miles of Federal Aid highways were involved. The States continuing weighing activities gave excellent coverage for the most important segments of the rural Federal Aid systems, those portions carrying the lion's share of the State's vehicle mileage. Some additional coverage was obtained where necessary on these systems but, for the most part, the existing weight studies gave adequate coverage. Therefore, it only became necessary to obtain data for the urban Federal Aid systems and the rural Federal Aid routes of lesser importance and usage.

In locating the weighing stations, considerable thought was given to so choosing them that the data collected would be representative of a considerable mileage of the system on which the station was located. Since incorporated areas of under 5,000 population are classed as rural for Federal Aid purposes, a number of stations were also located in these smaller communities to obtain data representative of these incorporated areas which are part of the rural Federal Aid systems.

In locating stations within urban areas, sites were chosen well within the city insofar as it was physically possible. Signed truck routes were avoided, as were those routes which serve primarily as access routes to commercial truck terminals, inasmuch as these are not representative of any significant mileage within urban areas and would therefore yield biased results as to vehicles weights and usage.

Since the State of Washington is split by the Cascade Mountains into two completely different regions climatically and economically, a greater number of weighing stations were actually operated than would have been the case had an equivalent highway mileage existed in a more homogenous type area. Wherever possible, stations were located at junctions of two Federal Aid systems in order to reduce the actual number of station operations. This was only done, however, where the junctions permitted weighing on more than one leg without interference to traffic and where traffic flow was such that vehicle operations on the different legs of the junction were independent and representative of the individual Federal Aid systems.

Locations in rural areas were much less of a problem than were those in urban areas, where, in order to locate well within the built up area of the cities, high traffic volumes were encountered, with considerable conjestion in some cases, as well as a number of parallel routes which afforded bypass opportunities. In order to make weighing operations possible under such circumstances, it was necessary in some instances to divert all those vehicles which were to be weighed to a side street where weight operations were conducted. Although this required additional man power, both for flagging operations and for police assistance for traffic control, it was the only practicable solution and permitted efficient and unhampered weighing to take place.

Both in rural and urban operations, transit companies and other scheduled bus operators were notified well in advance of the operation in order to permit the drivers to expect to be weighed and eliminate confusion that might otherwise have existed in the driver's mind. In every case, such vehicles were given first priority in weighing so as to cause as little difficulty in the maintaining of schedules as possible. The cooperation obtained from the drivers and operators was extremely gratifying.

Weighing operations were conducted for a full twenty-four hour period at all locations other than those of low traffic volume. Portable flood-lights were used to permit weighing to be conducted after dark. The volume of trucks passing during daylight hours was used as an indication as to whether the volume of trucks to be expected during the night hours would be sufficiently high to warrant operating for the full twenty-four hour period.

Weights were obtained from vehicles traveling in both directions, except where traffic volumes during peak hours required cessation of operations in the peak direction. In certain locations, particularly in urban areas where volumes were high over a prolonged period during the day, weighing operations were conducted in alternate hours in each direction.

At the locations operated, a total of 250,000 vehicles of all types passed the weighing stations. Slightly under 20% were of the types to be weighed and it was found possible to weigh slightly less than 50% of these. The State has not had the opportunity to analyze in detail the findings of the weighing operations. It is intended that for the State's use detailed study will be made to develop data on the differences in truck usage found on the different roadway systems. In addition, it is intended to make a detailed comparison of the findings of this 1957 weighing operation with the findings of the extensive urban and rural weighing conducted in 1949 in connection with a thorough study of vehicle usage and weights for the report "Taxing Washington Motor Vehicles Equitably for Highway Services", made by Dr. James C. Nelson for the Legislative Interim Committee.

Not only is the data collected by the State of Washington thought to be of extreme value to the national Section 210 Study, but it is also of great value to the State in its studies of equitability of the State level tax schedules. Obviously this is also true for all other states, also. It is hoped that this data of mutual usefulness will be utilized in just this way by the individual states. Never before has such a wealth of data been collected simultaneously at the State level for a study of such importance to the highway financing program. The differences which exist among states in legal restrictions, economy, enforcement, and in other elements which affect vehicle usage and weights makes it mandatory that weight and usage data be collected nationally if the findings are to be valid at the Federal level. Conditions which exist in the

State of Washington are undoubtedly not exactly duplicated in any other state. The State of Washington looks forward to the report on the findings of the national study as well as to those of the individual states.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1859 is identified as 1859 (HY 7) which indicates that the paper is contained in the seventh issue of the Journal of the Hydraulics Division during 1958.

VOLUME 84 (1958)

JANUARY: 1494(EM1), 1495(EM1), 1496(EM1), 1497(IR1), 1498(IR1), 1499(IR1), 1500(IR1), 1501(IR1), 1502 (IR1), 1503(IR1), 1504(IR1), 1505(IR1), 1506(IR1), 1507(IR1), 1508(ST1), 1509(ST1), 1510(ST1), 1511(ST1), 1512(ST1), 1513 WW1), 1514(WW1) 1515(WW1), 1516(WW1), 1517(WW1), 1518(WW1), 1519(ST1), 1520 (EM1)[c], 1521(IR1)[c], 1522(ST1)[c], 1523(WW1)[c], 1524(HW1), 1525(HW1), 1526(HW1)[c], 1527(HW1).

FEBRUARY: 1528(HY1), 1529(PO1), 1530(HY1), 1531(HY1), 1532(HY1), 1533(SA1), 1534(SA1), 1535(SM1) 1536(SM1), 1537(SM1), 1538(PO1)[c], 1539(SA1), 1540(SA1), 1541(SA1), 1542(SA1), 1543(SA1), 1544(SM1), 1545(SM1), 1546(SM1), 1547(SM1), 1548(SM1), 1549(SM1), 1550(SM1), 1551(SM1), 1552(SM1), 1553(PO1), 1554(PO1), 1555(PO1), 1556(PO1), 1557(SA1)[c], 1558(HY1)[c], 1559(SM1)[c]

MARCH: 1560(ST2), 1561(ST2), 1562(ST2), 1563(ST2), 1564(ST2), 1565(ST2), 1566(ST2), 1567(ST2), 1568 (WW2), 1569(WW2), 1570(WW2), 1571(WW2), 1572(WW2), 1573(WW2), 1574(PL1), 1575(PL1), 1576(ST2)[c], 1577(PL1), 1578(PL1)[c], 1579(WW2)[c].

APRIL: 1580(EM2), 1581(EM2), 1582(HY2), 1583(HY2), 1584(HY2), 1585(HY2), 1586(HY2), 1587(HY2), 1588 (HY2), 1589(IR2), 1590(IR2), 1591(IR2), 1592(SA2), 1593(SU1), 1594(SU1), 1595(SU1), 1596(EM2), 1597(PO2), 1598 PO2), 1599(PO2), 1600(PO2), 1601(PO2), 1602(PO2), 1603(HY2), 1604(EM2), 1605(SU1)[c], 1606(SA2), 1607(SA2) 1608(SA2), 1609(SA2), 1610(SA2), 1611(SA2), 1612(SA2), 1613(SA2), 1614(SA2)[c], 1615(IR2)[c], 1616 (HY2)[c], 1617(SU1), 1618(PO2)[c], 1619(EM2)[c], 1620(CP1).

MAY: 1621(HW2), 1622(HW2), 1623(HW2), 1624(HW2), 1625(HW2), 1626(HW2), 1627(HW2), 1628(HW2), 1629 (ST3), 1630(ST3), 1631(ST3), 1632(ST3), 1633(ST3), 1634(ST3), 1635(ST3), 1636(ST3), 1637(ST3), 1638(ST3), 1639(WW3), 1640(WW3), 1641(WW3), 1642(WW3), 1643(WW3), 1644(WW3), 1645(SM2), 1646(SM2), 1647 (SM2), 1648(SM2), 1649(SM2), 1650(SM2), 1651(HW2), 1652(HW2)[c], 1653(WW3)[c], 1654(SM2), 1655(SM2), 1656(ST3)[c], 1657(SM2)[c].

JUNE: 1658(AT1), 1659(AT1), 1660(HY3), 1661(HY3), 1662(HY3), 1663(HY3), 1664(HY3), 1665(SA3), 1666 (PL2), 1667(PL2), 1668(PL2), 1669(AT1), 1670(PO3), 1671(PO3), 1672(PO3), 1673(PL2), 1674(PL2), 1675 (PO3), 1676(PO3), 1677(SA3), 1678(SA3), 1679(SA3), 1680(SA3), 1681(SA3), 1682(SA3), 1683(PO3), 1684 (HY3). 1685(SA3), 1686(SA3), 1687(PO3), 1688(SA3)[c], 1689(PO3)[c], 1690(HY3)[c]. 1691(PL2)[c].

JULY: 1692(EM3). 1693(EM3), 1694(ST4), 1695(ST4), 1696(ST4), 1697(SU2), 1698(SU2), 1699(SU2), 1700(SU2), 1701(SA4), 1702(SA4), 1703(SA4), 1704(SA4), 1705(SA4). 1706(EM3), 1707(ST4), 1708(ST4), 1709(ST4), 1710 (ST4), 1711(ST4). 1712(ST4), 1713(SU2), 1714(SA4), 1715(SA4), 1716(SU2), 1717(SA4), 1718(EM3), 1719 (EM3), 1720(SU2), 1721(ST4)[c], 1722(ST4), 1723(ST4), 1724(EM3)[c].

AUGUST: 1725(HY4), 1726(HY4), 1727(SM3), 1728(SM3), 1729(SM3), 1730(SM3), 1731(SM3), 1732(SM3), 1733 (PO4), 1734(PO4), 1735(PO4), 1736(PO4). 1737(PO4), 1738(PO4), 1739(PO4), 1740(PO4), 1741(PO4), 1742 (PO4), 1743(PO4), 1744(PO4), 1745(PO4), 1746(PO4), 1747(PO4), 1748(PO4), 1749(PO4).

SEPTEMBER: 1750(IR3), 1751(IR3), 1752(IR3), 1753(IR3), 1754(IR3), 1755(ST5), 1756(ST5), 1757(ST5), 1758(ST5), 1759(ST5), 1760(ST5), 1761(ST5), 1762(ST5), 1763(ST5), 1764(ST5), 1765(WW4), 1766(WW4), 1767(WW4), 1768(WW4), 1769(WW4), 1770(WW4), 1771(WW4), 1772(WW4), 1773(WW4), 1774(IR3), 1775 (IR3), 1776(SA5), 1777(SA5), 1778(SA5), 1779(SA5), 1780(SA5), 1781(WW4), 1782(SA5), 1783(SA5), 1784 (IR3)[c], 1785(WW4)[c], 1786(SA5)[c], 1787(ST5)[c], 1788(IR3), 1789(WW4).

OCTOBER: 1790(EM4), 1791(EM4), 1792(EM4), 1793(EM4), 1794(EM4), 1795(HW3), 1796(HW3), 1797(HW3), 1798(HW3), 1799(HW3), 1800(HW3), 1801(HW3), 1802(HW3), 1803(HW3), 1804(HW3), 1805(HW3), 1806 (HY5), 1807(HY5). 1808(HY5), 1809(HY5), 1810(HY5), 1811(HY5), 1812(SM4), 1813(SM4), 1814(ST6), 1815 (ST6), 1816(ST6), 1817(ST6), 1818(ST6), 1819(ST6), 1820(ST6), 1821(ST6), 1822(EM4), 1823(PO5), 1824 (SM4), 1825(SM4), 1826(SM4). 1827(ST6)[c], 1828(SM4)[c]. 1829(HW3)[c], 1830(PO5)[c], 1831(EM4)[c], 1832(HY5)[c]

NOVEMBER: 1833(HY6), 1834(HY6), 1835(SA6), 1836(ST7), 1837(ST7), 1838(ST7), 1839(ST7). 1840(ST7), 1841(ST7), 1842(SU3), 1843(SU3), 1844(SU3), 1845(SU3), 1846(SU3), 1847(SA6), 1848(SA6), 1849(SA6), 1850(SA6), 1851(SA6), 1852(SA6), 1853(SA6), 1854(ST7), 1855(SA6)[c], 1856(HY6)[c], 1857(ST7)[c], 1858 (SU3)[c].

DECEMBER: 1859(HY7), 1860(IR4), 1861(IR4), 1862(IR4). 1863(SM5), 1864(SM5), 1865(ST8), 1866(ST8), 1867 (ST8), 1868(PP1), 1869(PP1), 1870(PP1), 1871(PP1), 1872(PP1), 1873(WW5), 1874(WW5), 1875(WW5), 1876 (WW5), 1877(CP2), 1878(ST8), 1879(ST8), 1880(HY7)[c], 1881(SM5)[c], 1882(ST8)[c], 1883(PP1)[c], 1884(WW5)[c], 1885(CP2)[c], 1886(PO6), 1887(PO6), 1888(PO6), 1889(PO6), 1890(HY7), 1891(PP1).

VOLUME 85 (1959)

JANUARY: 1892(AT1). 1893(AT1), 1894(EM1), 1895(EM1), 1896(EM1), 1897(EM1), 1898(EM1), 1899(HW1), 1900(HW1), 1901(HY1), 1902(HY1), 1903(HY1), 1904(HY1), 1905(PL1), 1906(PL1), 1907(PL1), 1908(PL1). 1909(ST1), 1910(ST1), 1911(ST1). 1912(ST1), 1913(ST1), 1914(ST1), 1915(ST1), 1916(AT1)[c], 1917(EM1)[c], 1918(HW1)[c], 1919(HY1)[c], 1920(PL1)[c], 1921(SA1)[c], 1922(ST1)[c], 1923(EM1), 1924(HW1), 1925(HW1), 1926 (PL1), 1927(HW1), 1928(HW1), 1929(SA1), 1930(SA1), 1931(SA1), 1932(SA1).

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c. Discussion of several papers, grouped by divisions.

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HW 1

JANUARY 1959 — 2 NO. HW 1
VOLUME 85 PART 2

Your attention is invited

NEWS OF THE HIGHWAY DIVISION OF ASCE

JOURNAL OF THE HIGHWAY DIVISION
PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

DIVISION ACTIVITIES
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

NEWSLETTER

January, 1959

THE CHALLENGE BEFORE HIGHWAY ENGINEERS
(An Editorial)

Construction of the 41,000-mile Interstate System of Highways is now beginning to roll. Already about 2,000 miles have been completed at a cost of over $1.5 billion, and another 3,200 miles costing nearly $2 billion are under construction.

This progress has permitted the American people to appreciate the many advantages of expressway design. Already the highway user has indicated he will expect all future major roads, not just those on the Interstate network, to be built with limited-access, offering the many advantages of this design. For example, the master plan prepared with the help of the Automotive Safety Foundation, for a 12,250-mile California freeway system to connect all cities in that state of over 5,000 population, is receiving quick acceptance. This network would be built in 20 years at a cost of about $10.5 billion.

Because of the many advantages of expressway layouts and the long-term savings for highway transportation that will result, the California proposal is only the beginning of a trend that will eventually lead to all important roads being of expressway layout. In view of this possibility, the question then arises: Are highway engineers, in their emphasis today on the Interstate System, taking adequate steps to provide modern design for all major routes? Funds are inadequate to have access control now for every project, but every new construction job on an important road might be planned for such control at a later date. This procedure may require extra land on numerous jobs for future interchanges. Other safeguards must also be taken.

This type of long-range planning will require vision, but it will provide untold benefits. Highway engineers should not get so busy on the Interstate system that they overlook future needs on all routes. The challenge is great for all highway planners; but it can be met.

Arch N. Carter
Chairman, Executive Committee

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Note: No. 1959-2 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, HY 1, January, 1959.
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NEW YORK CONVENTION—October, 1958

Among the many different programs presented by the Highway Division was a panel discussion on Traffic Engineering, conducted by the Committee of the same name. This was an interesting presentation which gave an indication of the methods of approach used in operational Traffic Engineering—which is, after all, the continuation of the engineering function after the design and construction of a street or highway has been accomplished.

NEW PUBLICATION

To help head off possible future shortages of highway engineers and technical specialists, a booklet entitled "A Career for You in Highway Engineering" is now ready for widespread distribution in high schools.

Sponsored by a joint committee of the Highway Division of ASCE and the American Association of State Highway Officials, and originally developed by this division's Committee on Highway Engineering Manpower, it is expected that distribution to high school students will be made principally by the State Highway Departments.

Until now no publication covering highway engineering has been generally available to high school students. Written for quick reading and well illustrated, the committee is hopeful that the booklet will encourage more students to enter civil engineering, particularly the highway field.

The initial limited edition was made possible by a grant and staff services of the Automotive Safety Foundation, Washington, D. C.

YOUR NEWSLETTER

This Newsletter is sent to members of the Society who have designated the Highway Division as one of their fields of professional interest. Members of the Division are invited to submit to the editor any contributions of interest for the Newsletter and are also urged to consider contributing to the technical work of the Division by preparing papers or discussions. Any member of the Executive Committee or of the technical committees will be glad to hear from possible contributors of technical papers for publication or for use at a meeting. Your editor will endeavor to publish the Newsletter items as they are received, subject of course to the policies of the Highway Division Executive Committee.

Newsletters are published separately from, but mailed in the same envelope with the Journals. This is to reduce mailing costs. Any material of general interest can be included, and graphs, tables and photographs can be reproduced just as they are in the Journal. The publication dates of the quarterly Highway Division Journal and Newsletter, and the corresponding deadline dates for contributions for each issue, are:

April issue - February 15
July issue - May 15
October issue - August 15
January issue - November 15

Comments, suggestions, and criticisms, besides specific items for the Newsletter, are requested and will be welcomed from the membership. Please address all communications to the Newsletter Editor:

Edmund J. Cantilli
Room 1539
The Port of New York Authority
111 Eighth Avenue
New York 11, New York

COMMITTEE NEWS

Executive Committee

Arch N. Carter has been elected Chairman, with John O. Morton as Vice Chairman. J. P. Buckley has been reappointed as Secretary. Newly appointed members are:

Wayne G. O'Harra 7306 N. Central Ave. Phoenix, Arizona	Board Contact Member	Appointment Expires 1959
Dean Harold B. Gotaas The Technological Institute Northwestern University Sheridan & Noyes Streets Evanston, Illinois	Board Contact Member	ASCE Research Committee

Harmer Davis completed his term of office with the committee in October, 1958. His work has been outstanding and it is hoped he will continue to give the Division the benefit of his knowledge and experience. It was due in large part to his leadership that the Highway Division has become more active in Society work.

Committee on Highway Engineering Manpower

This committee has completed its activities and has been disbanded upon publication of the booklet "A Career for You in Highway Engineering", which was described previously.

Traffic Engineering Committee

Some of the points discussed at the meeting of Tuesday, October 14, were the following:

1) Additional members will be added to the committee.
2) The committee will attempt to contribute to the work being done by the Society in developing highway engineering school curricula, especially in the addition of operations subjects.
3) The Committee will seek to sponsor objectives of the National Committee on Urban Transportation.
4) The members felt that there had been some notable progress in developing a better understanding of Traffic Engineering throughout all Civil Engineering fields. This was particularly evident from the large attendance and interesting discussion which took place at the Traffic

Engineering Session on the technical meeting program. It was felt that one of the best means of effecting a stronger understanding in relationships would be to develop and encourage more strong technical papers on traffic and highway transportation subjects. This is to be the major objective of the Traffic Engineering Committee in 1959.

Committee on Research

The Highway Division was represented at the "Conference on Basic Research in Civil Engineering" held in Washington, D. C., September 10-11, 1958, by Mr. C. D. Curtiss, Chairman of the Committee on Research of the Highway Division.

Mr. Curtiss advised the conference that the organization of the committee had just been completed the week before and that the purpose of the committee was,

> "To review the research developments of any one year and to select a few significant items which are estimated to have influence on future planning, design and development of any phase of highways and highway transportation. To prepare annually for publication by the ASCE a report summarizing such appraisal."

He also briefly described the AASHO Road Test in Illinois and stated that without doubt an important phase of the committee's activities would be to follow closely and report periodically on the progress of this test.

The committee has the following membership:

Mr. Kenneth Brady Woods
Professor, Highway Engineering
Purdue University
Lafayette, Indiana

Mr. Fred Burggraf
Director, Highway Research Board
2101 Constitution Avenue
Washington 25, D. C.

Mr. Jack Eugene Leisch
DeLeuw, Cather and Company
150 N. Wacker Drive
Chicago, Illinois

Mr. Francis Nelson Hveem
Materials and Research Engineer
Division of Highways
3435 Serra Way
Sacramento, California

Mr. Charles Dwight Curtiss
Special Assistant to Executive Vice President
American Road Builders' Association
World Center Building
Washington 6, D. C.

Committee on Cooperation with Local Sections

This committee met in New York on October 13, 1958, at which meeting the various tasks that could be accomplished by the Committee were discussed. These included the promotion of the establishment of highway divisions in the local sections; the promotion of the writing and presentation of papers on highway subjects; the provision of action by the Local Sections in regard to highway matters and matters affecting highway engineers, and the obtaining of the views of the Local Sections on highway matters of a national scope.

Committee on Increasing Highway Engineering Productivity

One of the objectives of this committee is to provide assistance to engineering educators in effectively covering new methods and devices in their courses of instruction in highway engineering.

In pursuing this objective, the committee has prepared a questionnaire, which it has sent out to the heads of the Civil Engineering Departments of 135 Universities, containing questions on the following general subjects:

A. Electronic Computers
B. Surveying and Photogrammetry
C. Office Practice
D. Outside Assistance

Following these questions is the request for individual views on:

1. Desired level of activity.
2. Areas for assistance.

The information requested on the questionnaire will be carefully analyzed and will determine largely the direction of the Committee's initial efforts.

MEETING CALENDAR

ASCE Meetings - 1959

February 19-23	Los Angeles Convention Contact: Lyman R. Gillis District Engineer, Division of Highways Box 2304, Terminal Annex Los Angeles 54, California
May 4-8	Cleveland Convention Contact: Alfred D. Yanda Hargett, Yanda & Barber 4500 Euclid Avenue Cleveland 3, Ohio
October 19-23	Washington Convention Contact: Carl E. Fritts Automotive Safety Foundation 200 Ring Building Washington 6, D. C.

Non-ASCE Meetings - 1959

January 5-9	Highway Research Board Washington, D. C. Contact: HRB, 2101 Constitution Ave. Washington 25, D. C.
January 28-30	California Street and Highway Conference 11th Annual Conf., Berkeley Contact: Inst. of Transp. & Traffic Eng'g. University of California Berkeley, Calif.
May 10-14	American Society of Planning Officials National Planning Conference Contact: ASPO, 1313 E. 60th Street Chicago 37, Ill.
September 14-17	Institute of Traffic Engineers 29th Annual Meeting, New York City Contact: ITE, 2029 K Street, N. W. Washington 6, D. C.